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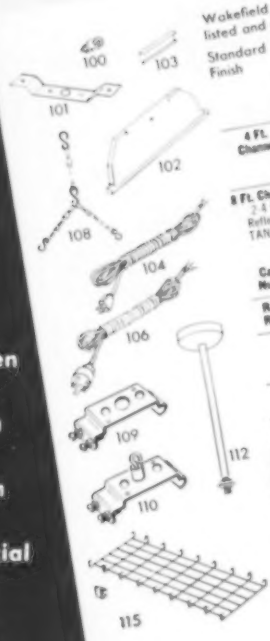

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Contents

315 A Special Message from the President — George J. Taylor

316 Footcandle Recommendations — Their Scientific Basis

317 Development and Use of a Quantitative Method for Specification of Interior Illumination Levels on the Basis of Performance Data — H. Richard Blackwell

354 Current Status of Some Other IERI Projects

359 Recommended Levels in Current Practice — Industry, Office, School

372 New Twists for Light Sources

374 Survey of Opinion on Future Trends in Lighting

382 Mercury and Fluorescent Team Up for Industry — Morgan Christensen and Quentin D. Dobras

389 Maintenance Factors and Features of Industrial Fluorescent Luminaires — George J. Taylor and R. D. Bradley

398 A Discomfort Glare Evaluator — S. K. Guth and J. F. McNelis

6A IES National Technical Conference Preprints

7A Lighting News

Here and There with IES Members, 16A; Scheduled Events, 17A; From the Desk of the President, 21A; It Seems to Me, 22A; About People, 22A; New Members, 30A

35A IES Publications

60A Index to Advertisers

61A IES Lighting Handbook, Third Edition

Sustaining Members — Refer to March 1959 ILLUMINATING ENGINEERING

Committee Personnel — Refer to April 1959 ILLUMINATING ENGINEERING

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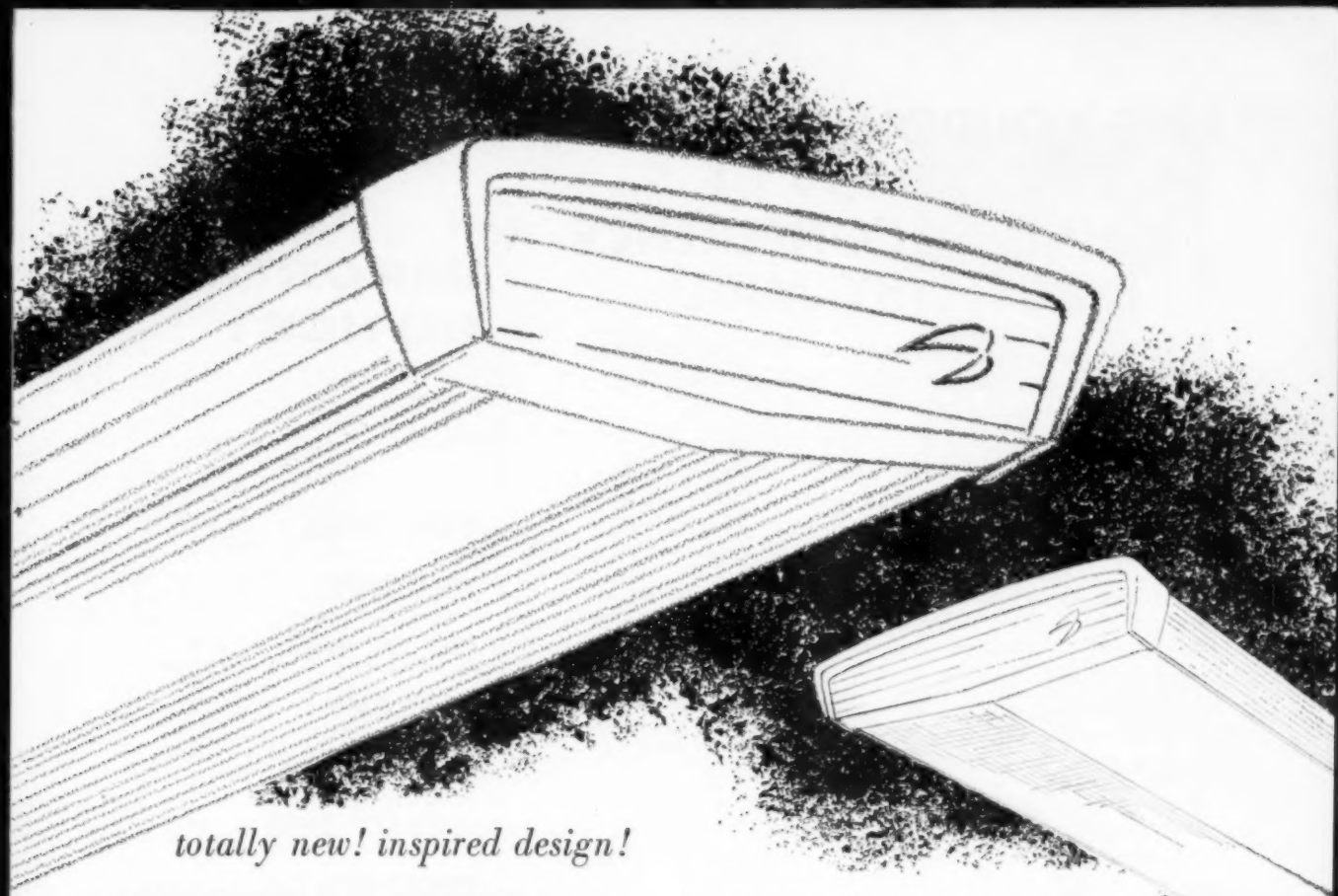

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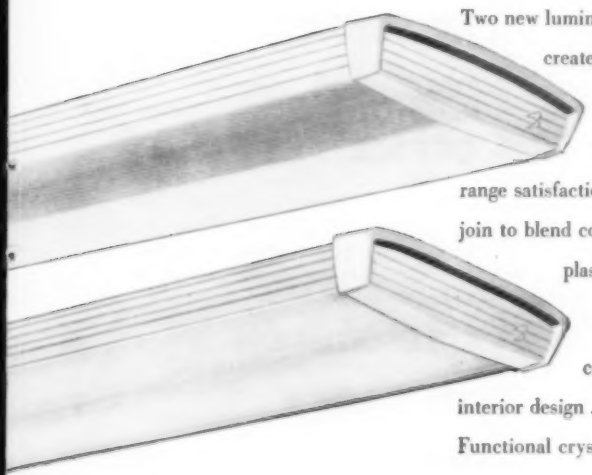

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A Special Message from the President

George J. Taylor
President, IES

Fabian Bachrach

WORD seems to have spread pretty much on its own momentum regarding the new IES footcandle levels and the research work on which they are based. This is good. Good, that is, if everyone who is concerned with lighting in any way fully understands their basis, and the procedures leading to their development.

In due time full understanding will undoubtedly be reached through publication of papers, reports and articles, and through personal presentations such as lectures, forums and panel discussion. Meanwhile, however, it might be of interest to again review some of the steps leading to the development of new recommendations, and also some of the more pertinent points of the footcandle levels themselves. Perhaps it is especially appropriate to review them in this issue, with the publication (beginning on page 317) of IERI Research Project No. 30 by Dr. H. R. Blackwell.

This Research Project Report was first presented by Dr. Blackwell as part of the Second Illuminating Engineering Research Institute Symposium, held at Dearborn, Mich. on March 3-4, 1958. Among the audience there were chairmen and members of IES technical committees, and members of the Society's Committee on Recommendations for Quality and Quantity of Illumination (popularly known as the RQQ Committee), who had previously studied the material. The symposium afforded these men, and the invited public also, a first-hand opportunity to appraise the methods and results of this latest research on quantity of illumination, in relation to their later deliberations on the footcandle recommendations.

The RQQ Committee further studied the research reports which had been publicly presented, in still another discussion session. From this they developed RQQ Report No. 1 (subsequently approved by Council and published in the August 1958 issue of ILLUMINATING ENGINEERING), offering their recommendations in connection with IES consideration of quantity of illumination.

Following this, an IES Technical Committee Forum was held, also at Dearborn, attended by chairmen and members of all technical committees. This was an extensive all-committee discussion of the reports presented by the research group (IERI), the RQQ Report No. 1, and their relation to current lighting practice.

After each committee had studied and discussed all factors applying to its field, and established footcandle values for the various job classifications, they then submitted reports to the IES Council for final approval. Council in its turn studied these reports and at its meeting in June 1958 approved revised footcandle recommendations for publication in the Third Edition of the *IES Lighting Handbook*.

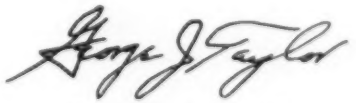
From this it should be clear that Dr. Blackwell's research team itself is not responsible for the establishment of any of the illumination levels; that all of the published footcandle values, new or old, are established by IES technical committee groups of lighting experts after consideration of all valid illumination research findings, known lighting principles, and vast field experience.

The Society may well take pride in the service it thus renders to the specifiers and users of lighting systems — in providing professional, unbiased guidance for the creation of a good seeing environment. And "good seeing environment" must include — to the extent the art will allow — sufficient lighting level for quick safe seeing of the specific task involved, control and direction of this illumination for visual comfort, and consideration of the reflectances for all surfaces within the room. To this pride might well be added satisfaction in seeing the fruits of this service over the years, in the increased output (with less strain) of industry and commerce, and the gradual but unmistakable improvement of the "visual standard of living" in all areas.

A review may also be in order of some features of the new recommendations themselves. Several of these are new to lighting practice:

- Recommended levels are now *minimum on the task at all times*. This is a departure from past recommendations of "average illumination" which was the average of measurements from wall to wall. The new recommendation says — *any* place in the room must have the light required for the task performed there.
- Maintenance Factor was formerly related to average "in service" illumination between new conditions and the worst (dirtiest and/or lamp burned-out) condition. *Now*, the maintenance factor is related to the *point below which it must not go*. The system must be cleaned and/or relamped when the illumination level falls below the recommended level.

As a final feature of this message, I would like to urge the education of all specifiers and users of lighting on the benefits of good lighting and on the principles, background and scientific basis of our recommendations, both as to quantity and quality. I urge this education be done on every possible occasion and by every member of IES. I say this in the sincere belief that they will thus be rendering a valuable service to men, women and children everywhere.



IES President, 1958-1959

FOOTCANDLE RECOMMENDATIONS—

Their Scientific Basis

Research Project No. 30 herewith presented, starting with the facing page, was a study to determine how much light we need for tasks involving various sizes, contrasts, times of seeing and degrees of accuracy.

Being an inquiry into the *amount* of light needed to perform various visual tasks, the research work concerned only *quantity* of illumination. Other factors of seeing, and of visual comfort, are the subjects of other investigations (see page 354). As with many valuable researches of the past—Cobb, Feree and Rand, Luckiesh, Moss, Weston, *et. al.* — the study resulted from a critical inquiry into the degree of difficulty the observer encounters in performing the task of seeing.

Its current significance to footcandle recommendations lies with the development of a Visual Task Evaluator and of a field factor to equate static laboratory conditions with dynamic "moving eye" field conditions. As President Taylor points out, on the previous page, the quantity of illumination recorded for 56 field tasks measured with the Visual Task Evaluator, are not "recommended footcandle levels." Weighed against tasks of comparable difficulty, and related to other known factors of seeing, they provided, together with other aspects of the research study, sufficient scientific basis for valid recommendations of illumination levels in numerous other areas. The footcandle recommendations, established by IES Technical Committees, using conclusions from this study as their scientific basis, are included in the *IES Lighting Handbook*, Third Edition (1959).

Details of this IERI Research Project on quantity of illumination have been outlined many times in the past year — at IES meetings, in the trade and technical press, and most notably in the comprehensive non-technical description by C. L. Crouch, in the August 1958 issue of ILLUMINATING ENGINEERING (see page 416, August 1958 IE). A re-reading of this now is recommended, in conjunction with the official report by Dr. Blackwell in this issue; likewise, a review of the RQQ Report, also published in August 1958. An outline of Blackwell's performance data, its application and its limitations, is also included in the new Handbook, beginning on page 2-22.

As will be noted from this, and many other discussions of the study, it should not be assumed that we have all the answers, plus-or-minus zero. Other researches are under way — on the relation of quantity of illumination and seeing for older eyes (Blackwell's subjects were for the most part college students) — on the relation of quantity of illumination and focusing — studies involving longer or shorter APS exposure — studies involving a different field factor from the 15 established for this work. The Field Task Simulator developed from these researches is an instrument for converting the static laboratory task into additional normal field conditions. More information will be sought to determine how well it represents other types of practical tasks.

There is good reason, however, to be excited by the progress made in illumination research. The method of specification of interior illumination levels developed by Dr. Blackwell and his research team provides a basis, backed by scientific experiment, for determining how much light we need.

Development and Use of a Quantitative Method for

Specification of Interior Illumination Levels

on the Basis of Performance Data

By H. RICHARD BLACKWELL

An eight-year program of research is reported here which has led to the development of a general method by which illumination levels may be determined for various practical tasks, based upon visual performance criteria. During these years, the author had the friendly guidance of the Technical Advisory Committee on Light and Vision of the Illuminating Engineering Research Institute, and he wishes to acknowledge his indebtedness in particular to Dr. Glenn A. Fry, Professor Everett M. Strong, Dr. Sylvester K. Guth, and Mr. Willard Allphin of this committee for many helpful suggestions. Mr. C. L. Crouch, Secretary of the Institute and Technical Director of the Illuminating Engineering Society, has been a strong motivating force in the conduct of this research, and has provided many extremely valuable ideas over the years. The lighting specification method was discussed on several occasions with the IES Committee on Recommendations for Quality and Quantity of Illumination, the members of this committee contributing various worthwhile suggestions. Similarly, Kirk M. Reid, then President of the Illuminating Engineering Society, contributed helpful concepts. Finally, the Basic Research Advisory Committee of the IERI provided valuable counsel. Of course, the author must accept full responsibility for the research program and for the present report, but in all fairness the many contributions of these active friends of lighting research should be acknowledged.

Introduction

The first report of the method was made in a detailed presentation at a Symposium sponsored by the IERI at Dearborn, Michigan on March 3-4, 1958.* Subsequently, a summary report of the method was presented at the National Technical Conference in Toronto on August 19, 1958. These reports not only described the basic elements of the method, but also recommended specific procedures to be followed in applying the method at the present time. The selection of procedures to be used currently was based upon all available relevant knowledge. The present report describes the method in its most general form, indicating the procedures recommended for current use. It goes beyond all earlier reports, however, by describing in addition what may well be the ultimate procedures for using the method, and by indicating the kinds of research needed to develop these procedures.

The method for specifying lighting levels reported in the present paper is obviously intended to supersede the less well-developed methods described earlier by the present author,[1,2] which depended upon performance data utilized in part for the present method.

The description of the general features of the method will reveal that we have much to learn concerning the details of visual performance. It should be emphasized, however, that the new studies reported here, together with the many important studies of the past, provide us with sufficient insight into the problem so that it is both wise and necessary for available performance data to be used now for the specification of lighting levels for various visual tasks.

The present report contains the following sections:

I. Characteristics of Visual Performance
II. Laboratory Performance Data for Standard Disc Targets
III. Field Factors
IV. The Visual Task Evaluator
V. The Standard Visual Performance Curve
VI. The Standard Lighting Specification Procedure
VII. Evaluation of Sample Visual Tasks
VIII. Future Developments of the Method

*Minutes of the Symposium may be obtained by addressing the Illuminating Engineering Research Institute at IES National Headquarters in New York.

I. Characteristics of Visual Performance

The visual system is primarily an information-assimilation system and visual performance should refer, therefore, to the rate at which information is assimilated. It is well known that the level of illumination of a visual task influences the capacity of the visual system to assimilate information, as do characteristics of the task such as the size and contrast of the "critical detail." The problem is to find some index of the capacity to assimilate visual information for use in specifying the lighting requirements of various visual tasks.

The visual system is not usually a passive information assimilator, but normally follows a complex adjustment procedure designed to extract information from the environment. The eyes normally fixate one point in the visual field, then the two eyes change accommodation and vergence so that clear images are produced in each eye and binocular fusion occurs for the two eyes. During the fixational pause, information is assimilated from the visual field. This information directs the eyes to a new position in space, with appropriate signals being sent to the oculomotor adjustment mechanisms to insure appropriate accommodation and vergence changes. New information is assimilated during this fixational pause which guides further adjustment of the oculomotor mechanisms, and so on. Under these conditions, the visual system is obviously a self-pacing servo-mechanism, the information assimilation capacity of which depends upon the efficiency of the oculomotor mechanisms as well as upon the characteristics of the task and the luminous environment.

Records of eye movements during self-pacing information assimilation reveal that the eyes do not scan the visual field in a simple orderly manner even when the material is simply ordered. For example, eye movements in reading continuous prose do not proceed regularly across the lines of words in the appropriate word order for the language involved. Instead there are repeated glances at some words, and fixation skips over other words. The skips are undoubtedly related to inferences which are drawn in some instances which make detailed examination of some words unnecessary; the repetitious glances are presumably related to the need for confirmation or assimilation of further information in other cases. The existence of these complex patterns of eye movements emphasizes the fact that the information assimilated by the visual system consists of many items which are complexly related and difficult to specify.

Measurements of the detailed characteristics of dynamic patterns of eye movements during reading agree in demonstrating that the eyes usually pause for a duration of about 0.225 second. Ginsburg[3] has shown that the eyes usually make four fixational pauses of this duration per second during continuous reading.

It is difficult to imagine reading through a pair of tubes which limit the field of view to a small zone immediately surrounding the fixational center. Thus, it seems apparent that information is assimilated from a sizable area of the visual field surrounding the fixational center during each fixational pause.

Clearly, then, informational assimilation is a complex process during normal dynamic use of the eyes. We have no easy way to specify the amount of information assimilated, since we cannot define the usual meaningful visual material in unambiguous informational units. Even if we could define the total information extracted during a complex visual task, we would have no way of defining the amount of information extracted in a particular fixational pause. Thus the rate of visual information-assimilation could not be specified independently of the speed and accuracy of oculomotor adjustment processes.

In order to specify lighting levels for various visual tasks, we need a quantitative index of visual capacity to assimilate information. It seems desirable to begin by simplifying the problem by considering the eyes to be incapable of motion. Under these circumstances, a controlled informational input can be supplied and the information-assimilation capacity measured unambiguously. The visual task must be capable of specification in terms of informational content. With this requirement in mind, a test object consisting of a luminous disc, presented on a background of generally uniform luminance, has been selected. When employing the test object, the observers are required only to indicate whether or not the presence of the disc has been detected. They are not required to identify other aspects of the target such as its size, shape, or color. Awareness of the presence or absence of the disc may be considered to be one item of information. (The term "bit" is avoided because of its precise significance in modern information theory; we have no evidence that the information concerning the presence or absence of our luminous disc

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A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 17-22, 1958, Toronto, Ont.
Author: Director, Institute for Research in Vision, The Ohio State University, Columbus, Ohio. Research conducted while the author was Director, Vision Research Laboratories, University of Michigan. Research sponsored in part as Projects Nos. 30, 30B, 30C, 30D, 30E, 30F, 30G and 30H of the Illuminating Engineering Research Institute. A summary of this paper is to be presented at the Brussels Congress of the Commission Internationale de l'Eclairage during the period of June 15-24, 1959.

may be defined in this specific manner.) The number of items assimilated per second is considered to measure the visual capacity, in units of assimilations per second (APS).

In actual experimentation, the time during which the disc target is presented is varied. The capacity of the visual system to assimilate the information represented by the disc target is derived from the time during which the information had to be presented for it to be assimilated. Thus, if the disc has to be presented for an entire second, the visual system is operating at a level of capacity corresponding to the assimilation of one item of information per second. If, on the other hand, the disc need be presented for only $^1/_{30}$ second, the visual system is operating at a level of capacity corresponding to the assimilation of 30 items of information per second. If the item of information can be assimilated in $^1/_5$ second or less, then it will be possible for assimilation to occur within one fixational pause. If, however, more than $^1/_4$ second is required for assimilation to occur, then the eye will have to spend more than one fixational pause assimilating the information. It may be considered extremely undesirable for a self-pacing servo-system, such as the visual system, when the level of visual capacity is reduced so that the item of information cannot be assimilated within one fixational pause. Use of repeated fixational pauses may be expected to disrupt the ordinary dynamic information-assimilation activity of the system.

A visual capacity to assimilate the item of information in less than $^1/_5$ second presumably means that the system can assimilate more than one item during a single fixational pause. It is difficult to imagine how the servo-system can operate unless it assimilates a considerable number of items of information during each fixational pause. For example, in reading, the system requires considerable information during each fixational pause to direct the movements of the eyes and the oculomotor adjustment processes.

It is not at present possible to describe the information-assimilation activity of the self-pacing visual system with any accuracy. However, studies conducted in the Vision Research Laboratories at the University of Michigan are suggestive in this connection.

Recently W. C. Clark and the author[4] attempted to evaluate the number of items of information which the visual system can assimilate per second from a single point in the visual field. The experiment involved disc targets which consisted of two very brief pulses, separated by a longer interval. The eyes were motionless during the presentation of the targets. The pulses were each only 0.0025 second long, and the separation between them was varied in different experiments from 0.0040 to 0.4750 second. In each case, the observers were required merely to detect the presence of the target and they were not required to recognize that two pulses had made up the target, much less to correctly estimate the length of the interval separating the pulses. The familiar temporal forced-choice method was employed, in which a target is presented in only one of four possible temporal intervals, each of two seconds duration. The observer had to indicate that he had discriminated the presence of the target by correctly identifying the interval in which it appeared. The contrast of the double-pulse target was varied from trial to trial and the accuracy of correct identification recorded. The contrast was determined at which the target is detected 50 per cent of the time, after correction for chance successes; this quantity is known as the threshold contrast.

The threshold contrast was measured for a number of different double-pulsed targets. It was found that when the two pulses were sufficiently close together in time, the threshold contrast was precisely one-half that which was required for one of the pulses. Thus, a single- and a double-pulse target of equivalent total energy are equally detectable. The existence of perfect temporal summation, as this is called, implies the absence of temporal resolution. (The situation is parallel to the more familiar situation in the spatial dimension, in which perfect spatial summation is revealed whenever two targets of different size but the same shape have equal total energy thresholds. As reported elsewhere[5] the presence of perfect spatial summation implies the absence of spatial resolution or visual acuity.) Perfect temporal summation was found whenever the double-pulses were separated by less than 0.02 second. As the temporal separation between the pulses was increased, the contrast required for detection increased continuously until, when the separation was 0.05 second, the threshold for the double-pulsed target was the same as the threshold for a target consisting of only one of the pulses. This situation revealed that there was no temporal summation between the two pulses. When the temporal interval between the two pulses was increased beyond 0.10 second, there was a small reduction in threshold contrast. This reduction may be explained quantitatively by assuming that the visual system succeeds in detecting the presence of the target whenever it detects the presence of either of the two pulses. Thus, the two pulses improve target detectability by what may be called probability summation. This suggests that the visual system is capable of re-cycling every 0.10 second. Infor-

mation assimilated in one brief cycle is separated from the information assimilated in a second brief cycle.

It is worth noting that clearly visible double-pulse targets in which the two pulses are separated by 0.10 second are usually seen as double. Thus, there are two rather different bases for believing that the visual system can resolve two items of information at the same point in space in $^1/_5$ second, providing there is at least $^1/_{10}$ second separating them. These data suggest that the visual system can assimilate two items of information from one point in space within the time usually devoted to a fixational pause. Since in self-pacing ocular activity there are normally four fixational pauses per second, it seems reasonable to suppose that at least eight items of simple information can be assimilated per second at a single point in the visual field. The fact that the human can recognize the presence of light flicker at rates up to 50 cycles per second certainly suggests that the visual system is capable of assimilating a great deal more than eight items of simple information per second, even from one location in the visual field. Of course, the successive items of information represented by the flickering light are not independent, and it is not possible for the human to determine the number of pulses per second beyond approximately 10 per second.

Another staff member of the Michigan group, E. R. Harcum, has recently reported the number of items of information which can be assimilated from different parts of the visual field, within the duration of a normal fixational pause. The eye was motionless for these studies, and spatial arrays of information were presented, consisting of multiple elements each of which could have one of two possible forms. These "binary" elements were used so that the target arrays would not have any meaning to the observers, in order to avoid ambiguities as to the amount of information actually assimilated. Provided the task elements had sufficient contrast and the general level of luminance was sufficient, arrays of information consisting of 8-12 elements could be correctly recognized. This means that the capacity of the visual system must be at least 10 items per fixational pause, or 40 items in the four fixational pauses the system normally makes per second.

The data of these studies suggest strongly that the visual system scans across space over time, so that first one and then another point in space is "interrogated" by a neural mechanism in the brain. The scan is repeated perhaps as many as 10 times per second. Thus, during a fixational pause, the entire visual field may be scanned at least twice with items of information being assimilated from various points in visual space during each neural scan.

It is not entirely justifiable to combine the Clark and the Harcum results quantitatively to evaluate the total number of items of information which can be assimilated from all portions of the visual field in a second. Direct use of both sets of data would suggest that at least 80 items of information can be assimilated per second. Of course, items of information may interfere with each other, thus reducing the total informational capacity. On the other hand, items may be related to each other in such a way that the informational capacity will be greater than the value suggested by these studies. Precise evaluations of the information-assimilation characteristics of complex time-space arrays of information must await further research. However, it would not seem unreasonable to suppose that the visual system can assimilate 30 simple items of information per second. In continuous reading, for example, surely the system extracts at least eight items of information during each fixational pause.

There is one further aspect of this conception of the visual system which deserves mention. If the eyeball remains fixed and an object moves rapidly across the visual field, the object is known to be more visible than if it had not moved. We believe that the visual system has auto-correlation sensitivity, so that regular time-space sequences, such as those produced by an object whose image moves across the retina, are unusually detectable. This aspect of the system is probably produced by the existence of spatially interconnected elements of the visual system.

There will usually be sufficient information present in the visual field so that the visual system can work at maximum capacity without assimilating all the information present. However, situations will occur in which the information is reduced to a level where the system cannot work at maximum capacity. It is, of course, a simple matter to produce conditions in the laboratory in which there is a severe limitation on informational content. Consider, for example, the situation in which a disc target is presented on a background field of otherwise uniform luminance. If the observer is required merely to detect the presence of the disc, we may limit the informational content to one item and we may prolong the presentation of the disc as long as we wish without adding information. Thus, presentation of a disc for a full second represents restriction of informational content to one item per second, which must certainly be considered a level of information far below the maximum capacity of the system. The item will usually be

assimilated during a single fixational pause, and there will be no further information gained during the next three fixational pauses which will normally be made during the one-second exposure of the disc. Under these circumstances, it is as though the information-assimilation system is idling. It is possible, of course, to reduce the visibility of the disc by reducing either its size or contrast until the disc will not be detected in less than a full second. Under these circumstances, we may surmise that all four of the fixational pauses to be expected during the one-second exposure of the target will be used for examination of the expected location of the disc. Studies by Clark and the author[4] suggest that disc targets exposed for durations longer than $^1/_5$ second are visible due to the probability summation mechanism described above, with separate fixational pauses representing the separate statistical events needed for this mechanism to operate.

Visual performance may also be limited by the requirement that a non-visual motor response be performed as an essential element in the information-assimilation sequence. For example, in some assembly-line inspection tasks, there is a sequence involving visual scanning of the objects to be seen, followed by some selective action with respect to the objects seen. The inspector may be required, for example, to reach out and remove objects which do not meet production standards. No matter how efficiently the inspector arranges his sequences of searching and removing, his capacity to assimilate information from the objects to be inspected may be reduced by the requirement that he respond appropriately to the objects being examined. This situation is to be contrasted with that encountered in continuous reading, in which the information may be assimilated as rapidly as the visual information-assimilation system can operate. It will be of interest, perhaps, to note that the performance data of Weston[7] represent visual performance under conditions in which there was an obvious response limitation. The observers had to cancel certain broken circles when they were seen. The inclusion of this non-visual motor response in the sequence of activities being studied undoubtedly had the result that the observers were unable to perform up to their maximum capacity to assimilate information.

There are different types of non-visual motor response requirements of visual tasks which will limit visual performance to various extents. For example, there are instances in which the observer will have to stop assimilating information completely until the motor response has been performed. Weston's task is probably of this type. Many inspection tasks, however, do not require that information-assimilation be completely stopped while the non-visual motor response is made. For example, it is often possible for the inspector to continue examining additional objects while he takes the requisite action with respect to an object which has already been examined. This can be accomplished whenever the non-visual motor response can be made without guidance by foveal vision. The selection of choice peaches from among large numbers of such fruit spread out on a moving belt is an example of an activity in which the non-visual motor response can be accomplished without foveal guidance once the select peaches have been located by foveal viewing.

II. Laboratory Performance Data for Standard Disc Targets

The analysis of the preceding section has described the visual information-assimilation process and has introduced the concepts of visual capacity to assimilate information, informational limitation, and response limitation. This analysis has suggested the desirability of "freezing" the eye so that the basic capacity of the visual system to assimilate information may be studied without involvement of the speed and accuracy of the ocular adjustment mechanisms of accommodation and vergence. In studying visual information assimilation, the capacity of the visual system needs to be investigated both when there is an informational limitation and when there is not. Response limitations on the capacity of the visual system should not be present. Visual capacity needs to be investigated at various luminance levels, for various simple visual tasks in which the informational content can be clearly specified.

Laboratory studies have been conducted since 1950 to provide the requisite basic performance data. The target consisted of a luminous disc, presented against an extended background of otherwise uniform luminance. Both target and background were "white light" of about 2850K color temperature. The observers were required to detect only the presence or absence of the disc, and were not required to report on other attributes of the targets such as size, shape, or color. In different series of experiments, the duration of the target presentation was varied from $^1/_{1000}$ second to 1 second, and the angular diameter of the disc was varied from about 1 to 60 minutes of arc. In each series of experiments, the background luminance was varied from zero to several hundred footlamberts. In each experiment, the visibility of the target was varied and an accuracy curve obtained.

Selection of the disc target was based on a number of considerations. It can be argued that the

simple brightness discrimination involved with this test object is the most basic discrimination, upon which other more complex discriminations are based. The information contained in the target can be confidently specified as a single item, since the only choice open to the observer is whether the target is present or absent. The target may readily be varied in difficulty over a range from easy to most difficult. Finally, previous experiments have shown that the accuracy data obtained with this target are easily handled by standard statistical methods.

The basic experiments were conducted between 1950 and 1952 and are reported fully elsewhere.[1] Series of experiments were conducted at exposure durations of 1, $^1/_3$, $^1/_{10}$, $^1/_{30}$, $^1/_{100}$, $^1/_{300}$, and $^1/_{1000}$ second. In each series, discs were studied with diameters of 0.802, 3.20, 12.8 and 51.2 minutes. Background luminance was varied from zero to 100 footlamberts in each series. Two well-trained observers made a total of 81,000 observations in experimental sessions lasting more than 12 months.

The basic task of the observers may be described briefly as follows:

The observers were seated before the open face of a lighted cube, as shown in Fig. 1. College students with entirely normal eyes were employed. They used normal binocular vision throughout the experiments. The cube was illuminated by frosted incandescent lamps arranged around the square aperture in the face of the cube at locations not visible to the observers. Direct illumination from these lamps fell upon the wall of the cube opposite from the observers, which served as the observation screen. This screen was approximately uniform in luminance for at least 30 degrees in all directions from the center, which was indicated by a diamond configuration of four orientation points clustered around it. Since the walls of the cube were coated with sphere paint, there was a considerable amount of diffuse illumination of the screen from the walls of the cube. The luminance of the screen was varied among experiments by varying the number and wattage of incandescent lamps. For very low luminances, special diffuse light-boxes were used with provision for the insertion of neutral absorbing filters to reduce the luminance of the sources without altering the geometry of illumination.

Figure 1. Observers seated in the basic laboratory testing room. The observation screen may be varied in luminance. The standard disc target is produced by transillumination of the screen from behind.

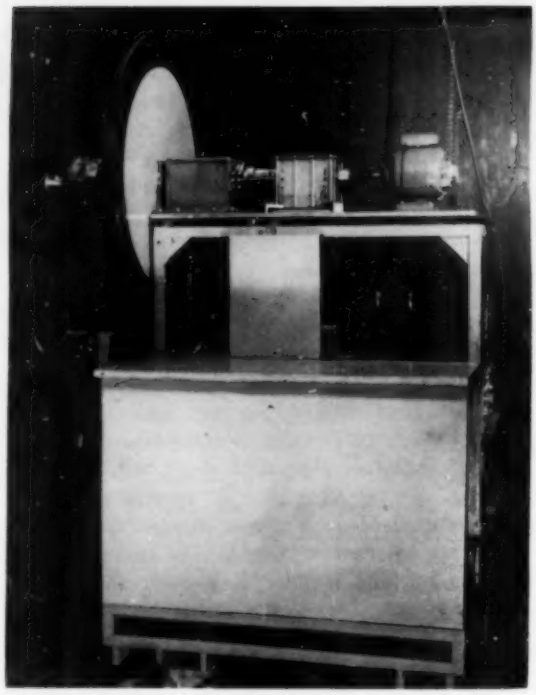

Figure 2. Projection apparatus and timer used to produce the standard disc targets.

The disc targets were produced by transillumination of the center of the observation screen, which consisted of a paper-thin translucent plastic coated with a very thin layer of sphere paint to reduce surface gloss. A special projector was used, as shown in Fig. 2, which consisted of an illumination system and a mechanical sector-wheel timer. The duration of the target pulse was determined by the size of an opening in the sector wheel. The size of the luminous disc was determined by the size of the aperture in a metal plate pressed against the rear of the screen. The luminance of the disc was adjusted by neutral absorbing filters mounted in the projection beam. Following the convention established by the author in 1946[5] contrast is defined by:

$$C = \frac{B_T - B}{B}$$

in which B_T = luminance of the target; and B = luminance of the background. In the present case in which the target is brighter than its background:

$$C = \frac{\Delta B}{B}$$

in which ΔB = the luminance increment produced by transillumination. The value of C varies between zero and infinity.

Observations were made by the temporal forced-choice psychophysical method.[8] With this method, the observers are required to indicate when they can detect the presence of a target by correctly identifying the temporal interval, of four possible intervals, in which it may have occurred. The observers are required always to select the most likely interval even when they are not confident of the correctness of their choice. In the present experiments, the temporal interval occupied by the target, and the precise luminance increment of the disc target were controlled by mechanical and electrical components of an automatic presentation equipment.[9] The scheduling of target presentations, and the recording of responses from the observers were accomplished by the timing equipment and relay racks shown in Fig. 3. Each experimental session consisted of 250 presentations of the target, 50 at each of the five values of target contrast.

The observers were given full knowledge of the size and duration of the target and of the moment

Figure 3. Automatic apparatus used to control the presentation of the standard disc targets and to record the responses made by the observers.

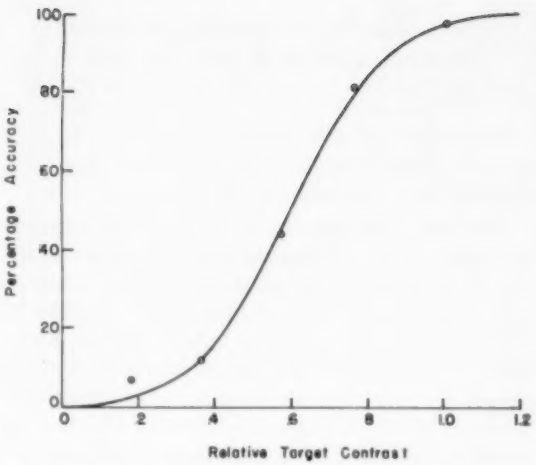

Figure 4. Sample accuracy curve: Response probability data fitted by a normal ogive.

during each temporal interval when the target would occur. Since the target was always presented in the precise center of the configuration of orientation points, the observers also had full knowledge of where the target would appear.

It is to be emphasized that the observers became very proficient in using the forced-choice procedure through extensive practice, and were able to detect the presence of targets of exceedingly small contrast.

The basic data recorded were the number of times each observer correctly identified the interval occupied by the target for each of five values of target contrast for a given set of conditions of target size, exposure duration, and background luminance. These data were analyzed in terms of the probability of correct response, p. Then, correction was made for the presence of correct responses due to guessing by the relation

$$p' = \frac{p - 0.25}{0.75}$$

in which p' = corrected proportion; and p = raw proportion. The relation between p' and target contrast is described by a normal ogive under all conditions.[10] The appearance of a sample set of data is illustrated in Fig. 4, in which percentage accuracy refers to values of p'. The solid curve drawn through the data points is a suitable normal ogive. The range of values of target contrast which result in less than 100 per cent and more than 0 per cent accuracy is known as the threshold range.

The process of data analysis consisted of fitting a normal ogive to the set of experimental values of p' obtained by each observer in each single experimental session by the probit analysis.[11] This analysis of each set of data yields the following:

$\dot{C}$ = the contrast corresponding to $p' = 0.5$
σ = the standard deviation of the ogive
$VR = \sigma/\dot{C}$
$\sigma_{\dot{C}}$ = standard error of $\dot{C}$
σ_σ = standard error of σ
σ_{VR} = standard error of VR.

The value of $\dot{C}$ represents the threshold contrast, the index of discrimination normally reported in psychophysical studies of this sort. The value of VR represents the change in contrast required to represent different accuracy levels with respect to 50 per cent accuracy level represented by the threshold. We will have occasion to utilize an accuracy level of 99 per cent for specification of lighting levels to provide adequate visual performance, since no one is interested in an accuracy level of 50 per cent in everyday seeing. The method of converting data from an accuracy level of 50 per cent to a level of 99 per cent will be discussed subsequently. As reported in the 1952 paper,[1] the value of VR was found to vary significantly as a function of target duration. Thus, when we wish to express our data at different accuracy levels, this variation in VR must be taken into account.

The raw threshold data are reported fully in graphical form in Figs. 2-8 of the 1952 paper. There is a separate graph for each of the seven exposure durations. In each graph, there are four curves relating threshold contrast to background luminance, one for each of the four target sizes. The raw data are shown, and empirical curves fitted through the data for purposes of identifying the general form of the relations found among the experimental variables.

Examination of the data points presented in the 1952 paper reveals that, in spite of the substantial number of experimental observations, there is considerable latitude in the shape of the curves which may be fitted through the points. Accordingly, considerable effort was devoted to the development of smooth curves to represent the functional relations more adequately than do the raw data. Consideration was given to the possibility of using simple analytical functions to describe the relations between threshold contrast and background luminance, since these relationships are directly related to the lighting specification problem, a procedure utilized some years ago by Moon and Spencer.[12] This suggestion was finally rejected because there is good reason to believe that the relations between threshold contrast, $\dot{C}$, and background luminance, B, obtained under our experimental conditions cannot be described by simple analytical functions. It is to be remembered that our observers utilized normal viewing with natural pupils. Thus, as B was varied, the pupillary area varied due to the photo-pupillary response. Not only does pupillary area influence the illumination falling on the retina, affecting visual performance, but changes in pupillary area also influence the effectiveness of illumination due to the well-known Stiles-Crawford effect. It is entirely apparent that the effect of B upon $\dot{C}$ cannot be expected to be a simple analytical function under these conditions. It may also be argued that the effect of B upon $\dot{C}$ may not be described by a simple analytical function even when a fixed pupil is used. The value of B presumably influences the concentration of photosensitive pigment which in turn influences visual performance by altering the effectiveness of the pigment in converting incremental light quanta into incremental neural impulses. In addition, the value of B influences the steady state neural noise in terms of which the neural incremental signal produced by the incremental light quanta must be discriminated. There is no reason to expect these two processes to be describable by a simple analytical function. In fact, careful measurements by Bouman[13] with a fixed pupil reveal that $\dot{C}$ and B are not related by a simple analytical function at all, but are related by a complex function which is not at all smooth. Thus, there appears to be no possibility of fitting smooth curves of $\dot{C}$ versus B to the data, unless we are prepared to do marked violence to the data.

Fortunately, there is a functional relationship which can be shown to be described by a simple analytical function which provides a rational foundation for data smoothing. This is the relation between disc diameter, α, and $\dot{C}$, for given conditions of exposure duration and background luminance. As discussed in detail elsewhere,[14] $\dot{C}$ may be related to angular disc diameter, α, by an element contribution function. This function predicts the condition that $\alpha^2\dot{C} = K$ for values of α small with respect to image blurring on the retina. At larger values of α, C decreases continuously with increases in α, but at a rate progressively less than the rate implied by the condition that $\alpha^2\dot{C} = K$. The element contribution function is a reflection of known spatial summative mechanisms in the visual system.

The smoothing of the relations between $\dot{C}$ and α for each set of values of exposure duration and background luminance has been described in detail in the 1955 paper[2] and need not be repeated here. We need only remark that contribution functions were found which fitted each set of data adequately. Changes were needed in the parameter of the contribution function for different values of luminance and exposure duration. It was required,

TABLE I — Smoothed Values of Log Threshold Contrast: Original Experiments.

α (minutes)	Log B (fL) 2.00	1.00	.00	−1.00	−2.00	−3.00
			$t = 1$ second			
1	−.798	−.631	−.256	.376	1.276	2.276
2	−1.400	−1.233	−.858	−.226	.674	1.674
4	−1.892	−1.743	−1.400	−.777	.123	1.123
10	−2.064	−1.958	−1.746	−1.179	−.279	.721
60	−2.128	−2.057	−1.960	−1.506	−.606	.394
			$t = 1/3$ second			
1	−.639	−.502	−.139	.466	1.331	2.326
2	−1.241	−1.104	−.741	−.136	.729	1.724
4	−1.750	−1.613	−1.287	−.687	.178	1.173
10	−1.979	−1.857	−1.665	−1.111	−.246	.749
60	−2.127	−2.039	−1.952	−1.469	−.604	.391
			$t = 1/10$ second			
1	−.461	−.236	.140	.764	1.629	2.616
2	−1.063	−.838	−.462	.162	1.027	2.014
4	−1.581	−1.375	−1.010	−.401	.464	1.452
10	−1.835	−1.704	−1.420	−.889	−.024	.964
60	−2.028	−1.943	−1.786	−1.407	−.542	.446
			$t = 1/30$ second			
1	−.170	.097	.534	1.182	2.032	3.027
2	−.772	−.505	−.068	.580	1.430	2.405
4	−1.287	−1.051	−.622	.029	.879	1.854
10	−1.576	−1.426	−1.061	−.473	.377	1.352
60	−1.835	−1.773	−1.511	−.989	−.139	.836
			$t = 1/100$ second			
1	.282	.542	1.012	1.712	2.532	3.482
2	−.320	−.060	.410	1.110	1.930	2.880
4	−.835	−.604	−.145	.543	1.363	2.313
10	−1.117	−.988	−.594	.049	.869	1.819
60	−1.414	−1.357	−1.068	−.461	.359	1.309

however, that these parameter changes be regular with respect to both luminance and duration, a rather stringent requirement. It was further required that plots of $\dot{C}$ versus exposure duration be smooth for various values of B. Meeting all these requirements left very little latitude in the data smoothing process, and led to curves relating $\dot{C}$ to B which were smooth, although by no means simple analytical functions.

Data which resulted from the smoothing process are presented in Table I. Data for exposure durations of $^1/_{300}$ and $^1/_{1000}$ second are not included, since our analysis of visual capacity in Section I suggested an upper limit of less than 100 APS for normal use of the eyes. Also only data for the five target sizes are included. Data for a number of other values of target size are included in the tables presented in the more complete report of these experiments.[15] The data obtained in the smoothing process represent the most adequate form of the experimental data first reported in 1952. Whenever the present tabular data disagree with raw data points or the empirical curves presented in the 1952 paper, the present data should be utilized. Incidentally, the tabular values presented here for the first time were utilized in constructing the curves contained in the 1955 paper.

During 1956 and 1957, additional experiments were performed to verify the form of the relationships between $\dot{C}$ and B, in the crucial range above 0.1 footlambert luminance, and to extend the data to somewhat higher values of luminance than were originally studied. The apparatus and procedures utilized were identical with those used in the earlier experiments. The original observers were no longer available. Six new college student observers with normal eyes were utilized in various of the experiments, following a moderately extended training with the forced-choice procedure. These experiments were conducted by Stanley W. Smith of the Michigan staff, who also served as one of the observers.

Series of experiments were conducted at each of three exposure durations: 1, $^1/_{10}$, and $^1/_{100}$ second; these durations were considered to cover the entire range of interest in connection with the specification of interior lighting levels. At each duration, five disc diameters were studied, as follows: 1, 2, 4, 10 and 60 minutes of arc. These values of target diameter were selected to be the same as those for which smoothed data were presented in Table I. Background luminance was varied in each series from about 0.1 to 300 footlamberts. The same group of four observers was used in all the experiments in a given series, but it was necessary to use different groups of observers in different series.

The results of these experiments are presented in Figures 5, 6 and 7 for 1, $^1/_{10}$, and $^1/_{100}$ second exposure durations respectively. Although the data never extended to luminances greater than 350 footlamberts, smoothed empirical curves have been fitted to the data which extend up to 3160 footlamberts. While this may seem to be a considerable

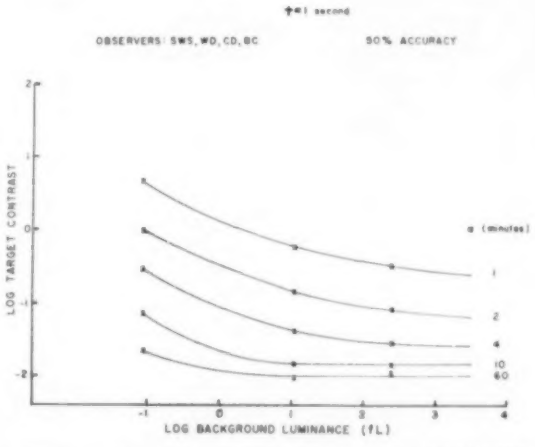

Figure 5. Threshold contrast data from the 1956-1957 experiments for a one-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

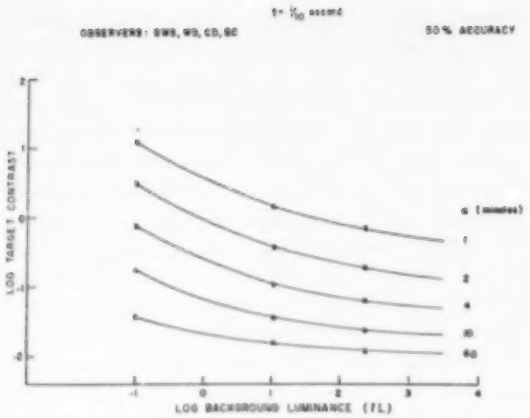

Figure 6. Threshold contrast data from the 1956-1957 experiments for a 1/10-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

extrapolation of the experimental data, it would appear from the figures that the extrapolations are not likely to be grossly inaccurate.

Comparison of these data with the data presented in the 1952 paper reveals that the functional relations between $\dot{C}$ and B are quite similar in the two series of experiments, as are the absolute values of $\dot{C}$ obtained at each value of B. (In making these comparisons, allowances must be made for the different values of α involved in the two studies.) The present data exhibit considerably less variability about the smooth curves fitted through them, as would be expected from the use of four rather than two observers.

The new data were used to extend the original

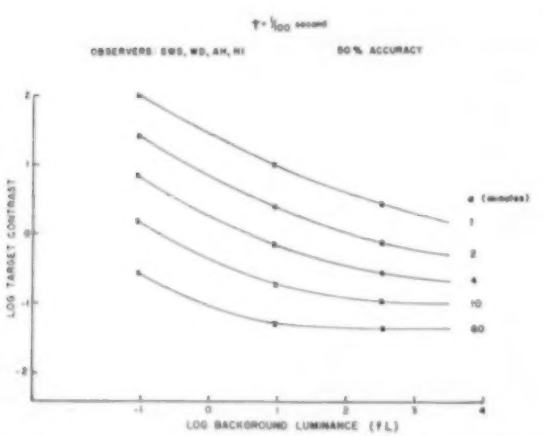

Figure 7. Threshold contrast data from the 1956-1957 experiments for a 1/100-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

data presented in Table I above, to background luminances up to 3160 footlamberts. The method involved determining the relative changes in $\dot{C}$ as a function of B beyond the 100-footlambert upper limit of the original data, and using these relative changes to extrapolate the data from the original study to higher luminances. Values of the log threshold contrast, relative to the value of $B = 100$ footlamberts, are presented in Table II for each of the five disc sizes, at each of the three exposure durations. When these values are added to the values of log threshold contrast presented in Table I, we have the extrapolated data for higher luminance level for the three exposure durations studied in the new experiments. It is possible, of course, to interpolate between the values presented in Table II, for intermediate values of exposure duration. Such interpolations were made for exposure durations of $^1/_3$ and $^1/_{30}$ second and are presented in Table III.

This procedure involves extrapolating the data on the original two observers to higher luminance levels, based upon the form but not the absolute values of the threshold data obtained with the six observers used in the more recent studies. This

TABLE II — Relative Log Threshold Contrast Values for High Background Luminance Levels.

Log B (fL)	α (minutes) 1	2	4	10	60
		t = 1 second			
2.00	.000	.000	.000	.000	.000
2.50	−.073	−.048	−.039	.000	.000
3.00	−.147	−.121	−.059	.000	.000
3.50	−.202	−.154	−.064	.000	.000
		t = 1/10 second			
2.00	.000	.000	.000	.000	.000
2.50	−.102	−.095	−.070	−.052	−.030
3.00	−.194	−.177	−.126	−.094	−.040
3.50	−.272	−.247	−.163	−.122	−.050
		t = 1/100 second			
2.00	.000	.000	.000	.000	.000
2.50	−.155	−.140	−.093	−.043	−.010
3.00	−.302	−.251	−.165	−.091	−.020
3.50	−.422	−.333	−.223	−.101	−.020

TABLE III — Relative Log Threshold Contrast Values for High Background Luminance Levels.

Log B (fL)	α (minutes) 1	2	4	10	60
		t = 1/3 second			
2.00	.000	.000	.000	.000	.000
2.50	−.088	−.072	−.054	−.026	−.015
3.00	−.170	−.149	−.092	−.047	−.020
3.50	−.237	−.200	−.114	−.061	−.025
		t = 1/30 second			
2.00	.000	.000	.000	.000	.000
2.50	−.128	−.118	−.082	−.048	−.020
3.00	−.249	−.214	−.146	−.092	−.030
3.50	−.347	−.290	−.193	−.112	−.035

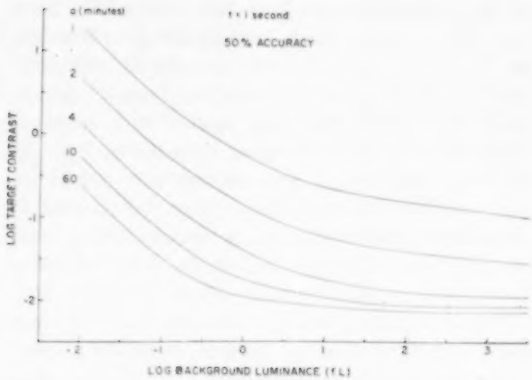

Figure 8. Smoothed threshold contrast curves for a one-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

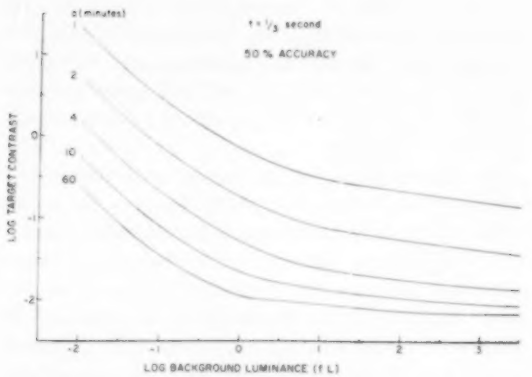

Figure 9. Smoothed threshold contrast curves for a 1/3-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

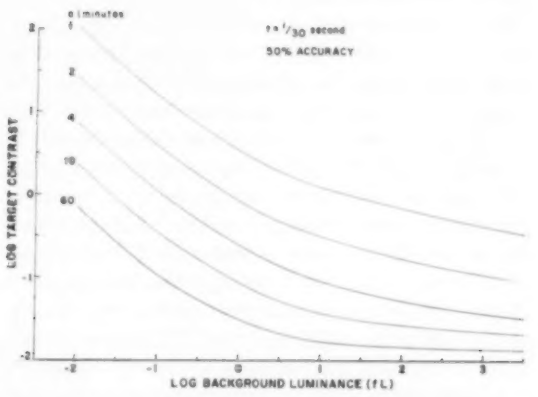

Figure 11. Smoothed threshold contrast curves for a 1/30-second duration. Each curve represents standard disc target whose diameter is indicated in minutes of arc.

procedure is necessitated by the fact that there are not sufficient data on any other observers under enough different experimental conditions to be useful. The fact that the data were not combined without regard to the specific observers involved in each set implies that the different observer groups gave data with somewhat different absolute values. The observers used in the 1956-57 study gave higher thresholds, a fact which is probably attributable to the fact that they had undergone considerably less training in the forced-choice procedure than had the two observers utilized in the original experiments.

The results of our manipulations of the data from the two studies consist of functional relations between $\dot{C}$ and B for the five exposure durations. These are shown graphically in Figs. 8-12. These

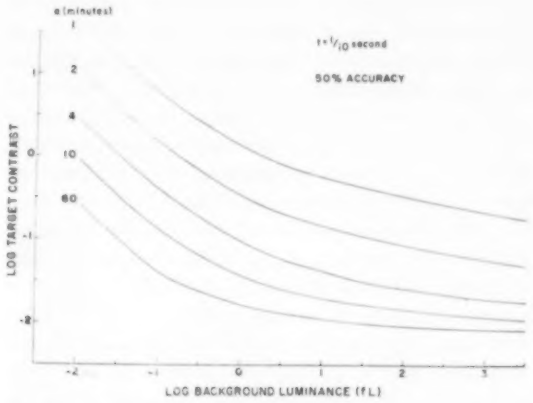

Figure 10. Smoothed threshold contrast curves for 1/10-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

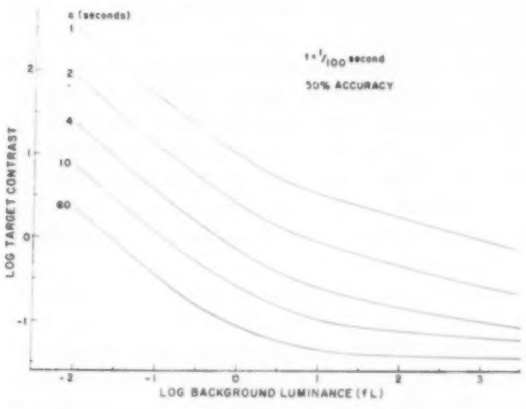

Figure 12. Smoothed threshold contrast curves for a 1/100-second duration. Each curve represents a standard disc target whose diameter is indicated in minutes of arc.

represent the final form of the laboratory visual performance data which will be used to provide the basis for the method of specification of lighting levels for various practical tasks.

III. Field Factors

It should be apparent from the description of the conditions under which the laboratory performance data were obtained that very favorable conditions were used for observing. The observers were highly skilled in using the forced-choice psychophysical technique, they had extraordinarily complete advance information about the target, and they had more than adequate time in which to align their lines of sight with the target and to adjust ocular accommodation and vergence. These conditions led to extraordinarily fine visual performance. For example, we may compute from Fig. 8 that the threshold contrast was 0.0073 for a 60-minute disc presented at high luminance for one second. Comparable data reported by the author in 1946 reveal that similar laboratory observing conditions give a threshold contrast value of 0.0028 for the 60-minute disc presented at high luminance for a period of from 8-10 seconds. These values are much smaller than values customarily assigned to the lower limit of threshold contrast, the value of 0.05 being a common value for example in the field of outdoor visibility. Clearly, it would be inappropriate to utilize these data directly as a basis for specifying lighting to provide adequate visual performance under the less ideal conditions of everyday seeing. The basic approach has involved studying the effects of the various differences between the conditions employed in the laboratory and those normally encountered in everyday use of the eyes, so that "field factors" can be developed to use in interpreting the laboratory data for practical problems.

A number of studies have been conducted since 1950 in which single variables differing between laboratory and everyday seeing have been studied. The results of these studies will be summarized to provide a basis for adopting reasonable values to use for field factors in applying the laboratory data reported in Section II to the problem of lighting specification.

Two separate experiments were concerned with what might be called the observing criterion. These experiments have been reported fully elsewhere[16] in another connection, so that a brief summary should suffice.

The first experiment involved comparing detection probabilities obtained with the forced-choice method with those obtained with the "yes-no" method, in which the observers indicated by "yes" or "no" whether or not they had detected the presence of the target. Data were obtained on four unusually experienced observers. These observers utilized the forced-choice and the "yes-no" procedures alternately from day to day in a series of daily experiments extending over more than 10 months. The target and background conditions were maintained constant during this period so that these observers had a staggeringly large amount of experience with this one detection situation. The general luminance was 4.71 footlamberts. The target subtended 18.5 minutes of arc, and was presented always seven degrees from the line-of-sight for about 0.072 second.

These observers had every opportunity to develop confidence in their forced-choice responses and to attach the verbal symbol "yes" to the experiences of dim and vague targets which led to correct forced-choice responses. Under these conditions, the difference between the probabilities of detection obtained with the forced-choice and the "yes-no" methods should be minimal. On the average the threshold contrast was 1.20 times as large with the "yes-no" method as with the forced-choice method.

The second experiment involved an evaluation of the extent to which the probabilities of detection with the "yes-no" procedure improve with practice. For this purpose, data were obtained under somewhat different experimental conditions on an entirely different group of observers. A group of 70 observers was used in several series of experiments in which different methods of training were evaluated. In all cases, a point source target was employed in known location on the line-of-sight. The exposure duration was 1.5 seconds. Background luminance varied in the different experiments from 17.9 to 18.7 footlamberts.

Each observer was introduced to the experimental situation with a set of instructions intended to elicit what might be called a "common sense criterion" of seeing. The observers were told: "We are going to turn on a light from time to time. If you see a light, say 'yes.' If you don't, say 'no'." (We did not inform the observers that we were presenting blank trials to evaluate their criteria.) If the observers asked, "How will I know?" we told them: "Oh, you'll know when you try it." These instructions were intended to keep the observers as naive as possible and to prevent them from developing a laboratory frame of reference.

Subsequently, these observers were divided into groups which were given different instructions and training. Some of these led the observers to improve their detection probabilities a great deal

more than others. In order to assess the relation between the common sense criterion and the usual laboratory criterion, we have compared the results of all the observers in the initial experimental session with results from the observers who utilized the most effective regimes of instructions and training. Large enough groups of equivalent observers are involved so that this comparison is not seriously affected by sampling differences. It was found that, on the average, the initial "yes-no" threshold was 2.00 times as large as it was after practice.

We may safely assume that the four highly experienced observers who participated in the first experiment were at least as effective in using the "yes-no" method as were any of the groups used for the much shorter time periods of the second experiment. On this basis, we can assume that the contrast threshold for naive observing with the "yes-no" method is at least 2.40 times as large as the threshold obtained by skilled observers utilizing the forced-choice method.

Common sense seeing is still seemingly quite different from laboratory observing, even when the "yes-no" method is used without practice. Common sense seeing does not usually occur in the threshold range where targets are sometimes seen and sometimes not seen. Of course, we can make quantitative corrections for different levels of accuracy and as noted above, in practical use of performance data, an accuracy level of 99 per cent is to be used. We may wonder to what extent common sense seeing is equivalent to laboratory observing at an accuracy level of 99 per cent. It would seem reasonable to suppose that the contrast threshold for common sense seeing would be still higher than the laboratory threshold, even for 99 per cent accuracy. It is, therefore, undoubtedly conservative to utilize a contrast multiplier of 2.50 to take account of the criterion difference between common sense seeing and laboratory performance with the forced-choice method.

The necessity for developing a conversion factor to correct our data from the criterion represented by the forced-choice psychophysical method to that of common sense seeing might suggest the desirability of having conducted our performance studies with a common sense criterion in the first place. Evidence reported elsewhere[16] indicates that the forced-choice procedure is a very desirable one for use in systematic and prolonged experimental work because of its reliability and independence from the effects of irrelevant psychological variables. Use of a common sense criterion makes repeatable data very difficult to obtain, since the observers are unduly influenced by their own opinions and by suggestions others make to them during the experiments.

A second important aspect of the difference between laboratory observing and commonplace seeing concerns the fact that the laboratory observers were able to direct their line-of-sight at precisely the location to be occupied by the target, and were able to adjust their ocular accommodation and vergence for optimal seeing. In a real sense, the visual field utilized effectively by the laboratory observers was reduced almost to a single point in space. In normal use of the eyes, there must be a considerable "receptive field" within which objects are visible, both because an observer cannot align his eyes exactly with an object of interest, and because a fairly sizable receptive field is necessary for sensory guidance of ocular accommodation and vergence. Even when an observer knows precisely where to look for an object, he normally has to move his eyes from point to point in visual space. The necessity for eye movements implies that objects must be visible off the line-of-sight, as well as on the center of fixation. It is not possible to evaluate precisely how large a receptive field is needed to promote sensory guidance for ocular accommodation and vergence, nor is it possible to specify how precisely an observer will normally be able to direct his line of sight. However, it would not seem unreasonable to require that the receptive field should normally extend two degrees in every direction from the fixation center.

In this connection, information is needed to determine how much greater the threshold contrast must be for an object to be visible two degrees from the fixation center, as well as at the fixational center.

Moldauer and the author[17] have recently reported a series of studies of the threshold contrast for targets presented in various locations with respect to the fixational center. The apparatus and procedures described in conjunction with the basic studies of visual performance in Section II were used with a few minor modifications. Provision was made that the orientation points could be moved with respect to the location of the target at the center of the observation screen. Thus, visual performance could be studied when the target was presented various distances away from the line of sight. A luminous disc target with a diameter of one minute was used throughout, and the exposure duration was $^1/_{100}$ second. At each of nine background luminance levels, studies were made of the threshold contrast both at the center of fixation, and at distances away from the fixational center measuring up to 12 degrees, along various meridians of the visual field. The luminances studied were 75 footlamberts, 1 footlambert, and seven values below .1 footlambert.

The relation between threshold contrast and dis-

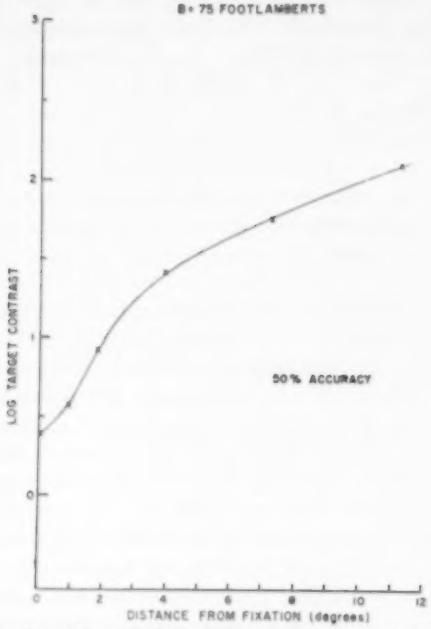

Figure 13. Threshold contrast data for a one-minute diameter disc target viewed at various distances from the fixational center.

tance from the fixational center, obtained at a 75-footlambert background luminance, is shown in Fig. 13, since this luminance level is most appropriate for our consideration here. It is apparent that the contrast threshold increases rapidly as the object to be seen is separated from the line-of-sight. In order to increase the receptive field over which an object may be seen, we must increase the contrast by a factor which represents the ratio of the threshold contrast for objects viewed at the edge of the desired receptive field to the threshold contrast for objects viewed on the light of sight. Sample values of this factor read from the curve in Fig. 13 are presented in Table IV. It is apparent that providing a reasonable receptive field requires a considerable increase in task contrast over the value which suffices when the object of interest need only be seen at a single point in the visual field. On the basis of the assumption made earlier that a receptive field of two degrees radius should be provided, we would need to use a contrast multi-

TABLE IV — Factors for Enlargement of the Receptive Field.

Radius of Receptive Field (Degrees)	Factor
1	1.66
1.5	2.57
2	4.00
3	7.41
4	11.0

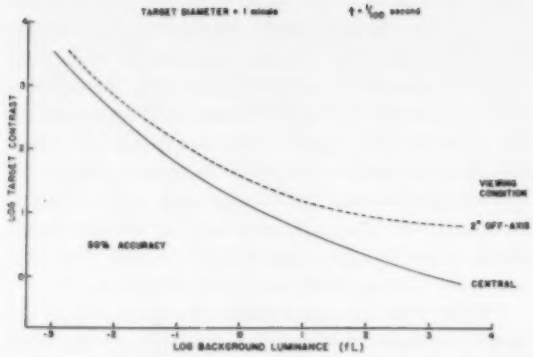

Figure 14. Threshold contrast curves for a one-minute diameter disc target for central viewing and for viewing two degrees off-axis.

plier of 4.00 to accomplish this enlargement of the receptive field.

The factor required to produce a given receptive field is not the same at all values of background luminance. To illustrate this point, data are presented in Fig. 14 for central viewing and for viewing off-axis by a fixed amount of two degrees. The experimental data do not extend beyond 100 footlamberts; accordingly, the curve for central viewing has been extended by means of the values presented in Table II. The curve for two-degree off-axis viewing has been extended by visual extrapolation. Fig. 15 contains values of the log factor representing the difference between the two curves in Fig. 14, at various values of background luminance. The factor varies sharply with luminance, having a value of four for a luminance level of 75 footlamberts.

Although this analysis suggests that the factor required to provide an adequate receptive field varies with the value of B, we shall have to ignore this complication in order to provide a workable system of field factors.

A series of studies has also been conducted to evaluate the influence of various psychological factors which differ between the conditions of the

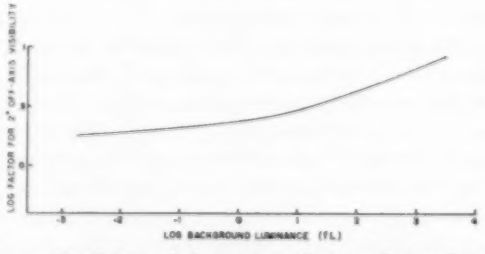

Figure 15. Values of the contrast factor relating thresholds for central viewing and thresholds for viewing two degrees off-axis.

laboratory and everyday use of the eyes. These studies have recently been reported elsewhere,[18] so that a brief summary should suffice. In one group of experiments, the effect of providing the observer with advance information as to the moment of occurrence of the target was assessed. Threshold measurements were made both with and without advance warning as to the moment of presentation of the target. It was found that the threshold contrast was 1.40 times higher when the observers were not given advance warning that a target was to be presented.

In a second group of experiments, the influence of the knowledge the observer possessed concerning the precise location to be occupied by the target was assessed. There were only two possible locations in which the target could occur. These positions were located equidistant from the center of fixation on either side. Different separations between the two possible locations in which the target might appear were investigated, varying from 0.25 degree to 8 degrees. The experiment compared the threshold contrast when the observers were not informed of which location the target would occupy, with the threshold contrast when they were informed of the eccentric target location in advance. The threshold contrast was always greater when the observer was not informed in advance of the location to be occupied by the target, the effect being greater the greater the separation between two possible locations. With the two locations each separated from the line-of-sight by three degrees or more, the threshold contrast was 1.31 times higher when the observer was not given advance knowledge of the target location.

Finally, a group of experiments was conducted to evaluate the effect of the frequency with which target objects occur. In the usual laboratory procedure, a target object is presented regularly each 10-30 seconds. In some inspection jobs, "targets" may occur with considerably less frequency than this. Studies were made in which the frequency of targets was reduced from one every 30 seconds to one on the average of every 15 minutes. (In neither case were the observers warned in advance when the targets were to be presented.) The threshold contrast was 1.19 times higher when the frequency was reduced. Of course, the existence of only one target object every 15 minutes may be considered rather extreme, so perhaps a factor of 1.10 would be more representative of the conditions to be expected in actual everyday use of the eyes.

There is no really satisfactory basis upon which the joint effect of various of these factors related to the psychological conditions of observing can be assessed. Perhaps all we can do is to estimate that the existence of some of these differences will produce an increase in contrast threshold of at least 1.50, and that the existence of them all may be expected to increase threshold contrast by at least 2.00.

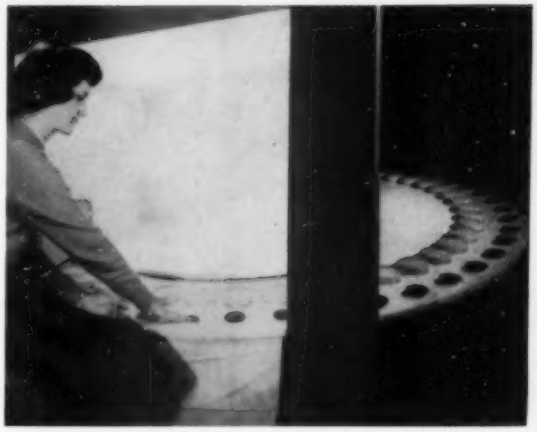

Figure 16. Observer seated in the observation booth of the Field Task Simulator. The wooden platform is shown with the circular plaques and the adjacent indicator buttons.

These studies of the effects of various differences between laboratory observing and everyday seeing are not entirely definitive, but they do assist us in identifying the variables differing between laboratory and everyday use of the eyes, and they provide estimates of the numerical effects which these variables produce. Before attempting to develop field factors for use in specifying lighting for various tasks, we decided to attempt to evaluate the field factor as a whole for some task representing realistic use of the eyes. For this purpose, we developed a "Field Task Simulator," and studied a visual task which could be directly compared with the laboratory task which had been previously subjected to extensive study.

The Field Task Simulator is shown in Fig. 16. The observer is seated in a small light booth, illuminated from overhead through a translucent ceiling. She looks downward at a series of circular plaques, each four inches across. There are 50 of these plaques, mounted around the circumference of a seven-foot wooden platform. The platform extends under the observation booth and considerably behind it, as shown in Fig. 17. The platform may be set into motion, revolving about the shaft shown behind the observation booth in Fig. 17. As the platform revolves, the plaques are moved across the observation booth beneath the eyes of the observer. The walls of the observation booth, the surface of the wooden platform, and the top surfaces of the plaques were painted with sphere

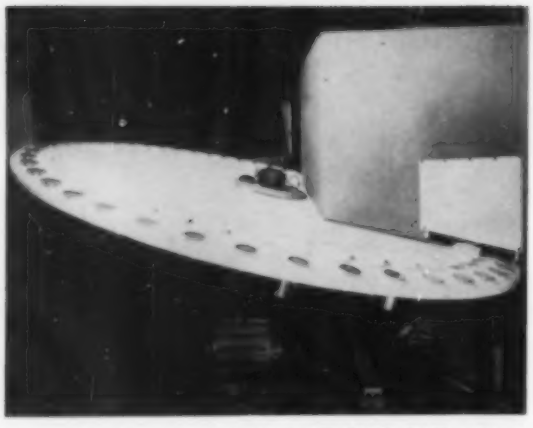

Figure 17. Over-all view of the Field Task Simulator. Wooden platform is made to rotate about the centrally located shaft, thus moving the plaques through the observation booth.

paint. The plaques actually were composed of paper-thin translucent plastic, which could be transilluminated to produce luminous disc targets such as were used in the original laboratory experiments. Metal apertures behind the plastic determined the size of the circular luminous disc targets. Illumination of the target discs was provided by lamps mounted in metal receptacles beneath the plaques. In the absence of transillumination, the plaques appeared to be uniformly bright and were regarded as "perfect." When the lamp below a given disc was turned on, the small spot of light produced in the center of the face of the plaque was considered to be an imperfection in the plaque. The experimenter could vary the size of a luminous disc target by changing the metal aperture placed beneath the plastic. The luminance increment, and hence the target contrast, could be varied by moving the lamp closer or farther from the metal aperture, and by the use of gelatin and glass neutral absorbing filters.

The task of the observer was to inspect all 50 of the plaques for the presence of "imperfections." In a given series, the entire 50 plaques were made to pass beneath the observer's eyes. Discrimination of the presence of a bright spot on the face of a plaque was indicated by the observer depressing the gray button located adjacent to the plaque possessing the imperfection. The experimenter could turn on the lamp beneath any of the plaques. There were usually two or three of the luminous discs turned on at any one time. On occasion, the number was as small as one or as large as six. Since the discs were set for the threshold range, the observer almost never detected the presence of more than two or three discs.

It is important to emphasize that the observer did not have to respond to an imperfect plaque before she could begin to examine the next plaque. She could easily depress the indicator button with the visual guidance provided by peripheral vision. Thus, the observer tended to begin to examine a plaque as soon as it entered the observation booth from the left-hand margin. Because of the larger angular movement of each plaque, the observer had to track the plaque while examining it. The observer had to perform her examination of each plaque quite rapidly in order not to miss some of the plaques. At the same time, she had to successfully depress the button adjacent to any imperfect plaques before the plaque disappeared from the observation booth on the right-hand margin. Six plaques were visible to the observer within the observation booth at one time.

Measurements were made with two speeds of revolution of the wooden platform. In the slower speed, the platform completed a full rotation in 50 seconds. In the faster speed a full rotation was accomplished in only 20 seconds. The observers were able to learn to operate the Simulator at both speeds without response limitation of their visual performance.

Measurements were made at each of a number of levels of luminance of the wooden platform as viewed from within the observation booth. At each luminance level, the contrast of the luminous discs was varied to provide variable accuracies within the threshold range. The actual luminance increment of each disc target was measured with a photoelectric photometer which was calibrated in terms of a visual photometer used to measure the intensity of small sources by measuring the illumination produced by the source on a standard test plate. The luminance increment produced by each disc was computed from the intensity and the measured size of the disc.

The observers made so few errors by depressing buttons corresponding to perfect plaques that the probabilities of correct response can be analyzed without concern for corrections for successes due to "chance." The response data were analyzed by fitting normal ogives to the values of accuracy probability, expressed in terms of a scale of disc contrast. Because of the relative paucity of experimental data, the ogives were fitted by eye and only values of the threshold contrast were obtained, corresponding to an accuracy level of 50 per cent. Three well-trained observers were used in all.

The results obtained with the slower rate of rotation of the wheel are presented as the data points in Fig. 18. Since there were 50 plaques to be examined in 50 seconds, these data are considered to

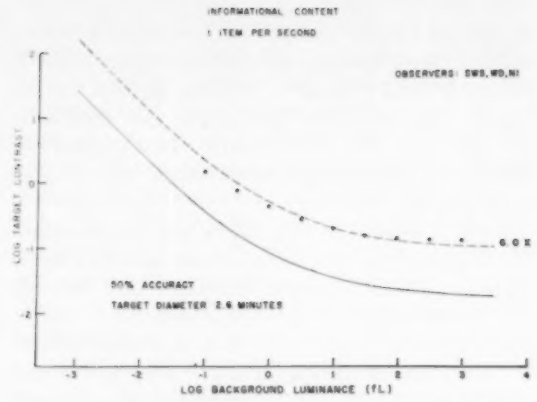

Figure 18. Threshold contrast data from the Field Task Simulator, for a rotational speed yielding plaques at the rate of one per second. The solid curve represents a threshold curve interpolated from the basic laboratory data. The dashed curve represents the laboratory contrast values multiplied by a factor of 6.0

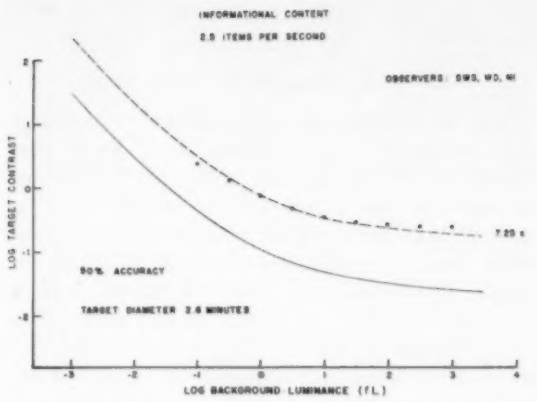

Figure 19. Threshold contrast data from the Field Task Simulator for a rotational speed yielding plaques at the rate of 2.5 per second. The solid curve represents a threshold curve interpolated from the basic laboratory data. The dashed curve represents the laboratory contrast values multiplied by a factor of 7.25.

represent an informational content of one item per second. The angular size of the discs used in this experiment was 2.6 minutes. Note that the values of threshold contrast vary with background luminance in the approximate manner to be expected from our earlier performance data. In fact, the solid curve represents results from the original laboratory studies reported in Section II, in which $\alpha = 2.6$ minutes and in which the exposure duration of the single flashes was one second. Comparison between the simulator data and these particular laboratory data should reveal the over-all effect of the many differences between the laboratory and the simulator, when the informational content was the same. As expected, the simulator data occur at higher values of target contrast, representing the fact that visual performance is inferior in the simulator.

The dashed curve fitted through the data points was constructed by multiplying each value on the solid curve by a constant equal to 6.0. (Since the scale of contrast in the figure is logarithmic, this is accomplished simply by moving the solid curve vertically by an amount equal to the logarithm of 6.0.) The dashed curve provides a fairly reasonable fit to the data, revealing that on the average 6.0 times as much contrast was needed in the simulator as in the laboratory experiment.

The data obtained in the study with the more rapid rotation of the platform are presented in Fig. 19. In this case, the informational content is considered to be 2.5 items per second. The solid curve in this case represents data from the original laboratory study, corresponding to an exposure duration of single target flashes equal to 0.4 second. These data were interpolated from the families of smooth curves produced by the data-smoothing process described in Section II. The dashed curve fitted through the simulator data in this case was constructed by multiplying each value on the solid curve by a constant equal to 7.25. As before, the dashed curve provides a reasonably adequate fit to the data points.

These data suggest that the over-all field factor required to compensate for all the many differences existing between the laboratory conditions and those of the simulator varies between 6.0 and 7.25. It is interesting to relate this to the values suggested by the series of studies of the variables which might be expected to contribute to a field factor. It is to be emphasized at once that the criterion factor is not involved since in both the simulator and the laboratory study trained observers utilized what amounted to a forced-choice procedure. The factor of from 6.0 to 7.25 can be understood as due to a factor of perhaps 4.0 to provide a receptive field of suitable size, and a factor of from 1.5 to 1.8 for psychological factors such as lack of knowledge when and where the target objects would appear. It is interesting to note that factors for lack of knowledge as to when and where the target would appear would equal 1.83 if multiplied together, a value which agrees remarkably well with the values actually obtained. Of course, this agreement could be easily lost had we selected a different value for the factor used to enlarge the receptive field. Still, this comparison provides some understanding of what might go to

make up field factors required under actual field conditions.

IV. The Visual Task Evaluator

The basic philosophy of the method for specifying lighting levels on the basis of the visual performance data summarized in Section II involves determining the standard disc target which is equivalent in visual difficulty to each practical task of interest. Once this equivalence has been established, the performance data for standard discs may be used to determine the lighting required to provide a desired criterion level of visual performance. The Visual Task Evaluator is an optical device designed for establishing the equivalence of practical tasks and standard disc targets.

The original Visual Task Evaluator (VTE) was designed to permit several different modes of operation, for evaluating their relative merits. The design of this device is to be credited primarily to my associate, Benjamin S. Pritchard. Design considerations of instruments of this sort will be discussed in a forthcoming paper, so that a brief description of the operating procedure will suffice here. The present model is clearly a research model, and is in no sense supposed to be a practical device for production and widespread usage. The optical diagram is presented in Fig. 20. A photograph of the device is presented in Fig. 21. The optical components are mounted on a rigid aluminum table in individual mounting units which made it a comparatively simple matter for modifications to be made in the optical design.

The operator of the VTE first views the practical visual task through one optical system and adjusts it until it is barely visible. He then views a standard disc target through another optical system and adjusts it until it is barely visible. Equivalence of the two tasks is established by the fact that both are set for threshold visibility. The method by which this operation is accomplished will be described in some detail.

With reference to Fig. 20, when the practical visual task, *P*, is viewed, the removable mirror is removed and the operator views the task through one of two possible objective lenses. The task is seen within the inner field of a photometric comparator cube consisting of inner disc and outer annulus fields. The task is reduced to threshold visibility by means of a partially silvered circular mirror of variable optical properties, kindly provided for our use by Professor D. M. Finch of the University of California. The transmittance of the mirror varies continuously "around the clock." The reflectance varies "around the clock" in the opposite direction. This variable "wedge" is so designed that the sum of its transmittance and reflectance are approximately equal at all points. The wedge is used to reflect a uniform light veil over the practical task. Thus, as the wedge is turned, the contrast of the task is varied continuously while the luminance remains constant. Finch has reported on the detailed characteristics of these wedges elsewhere,[19] so that a detailed description of the wedge is not required.

The design of the VTE employs a single internal lamp for a variety of related purposes. As shown in Fig. 20, the lamp provides the light veil, *V*, for

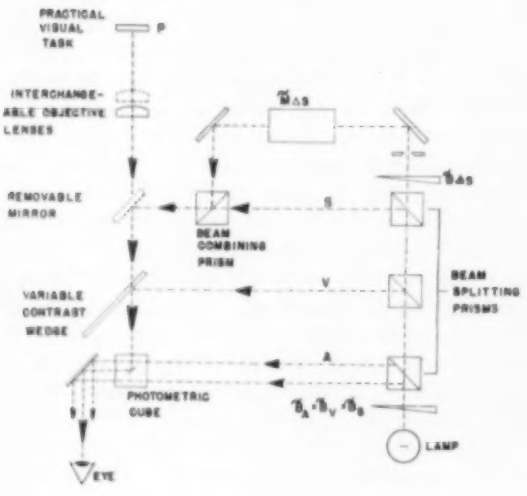

Figure 20. Optical schematic diagram of the Visual Task Evaluator (VTE). See text for explanation.

Figure 21. Photograph of the Visual Task Evaluator (VTE). A sample reading task is mounted before the device, lighted by a 35 mm slide projector. The Macbeth Illuminometer is used to measure the average task luminance.

reducing the contrast of the practical visual task. It also provides light for illuminating the annulus, which appears around the inner photometric field occupied by the practical task. The value of V was set equal to A with the wedge turned to 100 per cent reflection when the VTE was originally calibrated and this equivalence is not disturbed in any way by the use of the device.

The actual operating procedure has a further complication. As we shall see, it is necessary for the value of V to be set equal to the average luminance of the visual task. This was originally accomplished by having the operator set the luminance of the annulus, A, equal to the luminance of the inner field containing, as it did, a complex object and its background of non-uniform luminance. The precision of these settings was unsatisfactory. Accordingly, it was decided that the inner field should be defocused to facilitate the photometric match. A second objective lens was obtained which focused the visual task in the plane of the pupil of the operator's eye. Such a Maxwellian-view system provides a perfectly uniform inner field so long as the eye is centered with respect to the optical system. Under these circumstances, it was possible to match A to the inner field with satisfactory precision. Thus, the procedure involved: (a) inserting the blurring lens and setting A to match the inner field; (b) inserting the imaging lens and adjusting the contrast wedge until the task was barely visible.

The next step in the procedure involved leaving the contrast wedge in the position at which it was set to bring the practical task to threshold visibility, and interposing the removable mirror. This mirror is used to replace the view of the practical task in the inner field of the photometric comparator with a view of a standard disc target. The background for the standard target, S, is uniform in luminance and is produced by the lamp used to produce V and A. The luminance increment representing the standard target, ΔS, is also produced by the same lamp but there is an independent control over the luminance of the increment by a neutral density wedge, ground to varying thickness from a piece of Chance neutral glass. Adjustment of the luminance increment, ΔS, varies the initial contrast of the standard disc target. When the standard target is viewed through the variable contrast wedge, the initial contrast of the disc is reduced by the wedge to an extent dependent upon the position of the wedge.

One method of operation of this stage of the VTE involved fixing the size of the standard disc and adjusting the value of ΔS to threshold visibility, with the contrast wedge set for the value previously used to reduce the practical task to threshold visibility. The initial contrast of the standard disc represents the equivalence value desired from the VTE procedure. That is, the initial contrast of the standard disc together with the angular size of the disc, define the standard disc of visibility equivalent to the practical task.

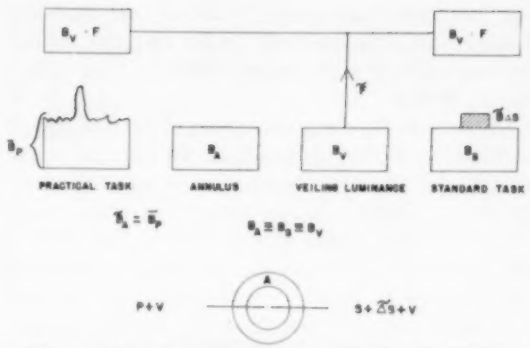

Figure 22. Conceptualization of the operating principles of the Visual Task Evaluator. See text.

The basic operations implied by this procedure for using the VTE are represented schematically in Fig. 22. The practical task, P, has an average luminance, $\overline{B}_p$, which represents an average of the non-uniform luminance of the critical detail and immediate surround of the task. The luminance of the annulus, B_A, is set equal to this average luminance in the first step in the procedure. Then $\overline{B}_A = \overline{B}_p$, where $\sim$ implies that the quantity may be adjusted to any desired value. The adjustment of B_A to equal $\overline{B}_p$ implies that $B_V = B_S = \overline{B}_p$ since $B_A \equiv B_S \equiv B_V$. The setting of the contrast reduction factor, F, of the wedge varies the amount of veiling luminance interposed over $\overline{B}_P$ and also over B_S and $B_{\Delta S}$, the luminance increment of the standard disc. Then, the luminance, $B_{\Delta S}$, is varied until the standard task is at threshold luminance when viewed through the amount of veiling luminance required to reduce the practical task, P, to threshold. It is assumed that the practical and standard task which are equally visible at threshold are also equally visible in the absence of the veiling luminance. Standard and practical tasks, set equivalent with the veiling luminance, have been examined in the absence of the light veil. It is difficult to evaluate the degree of equivalence of tasks both of which are well above threshold but, to the extent that such judgments can be made, there does not appear to be any violation of this assumption.

(Incidentally, the diagram in the lower section of Fig. 22 illustrates the appearance of the photometric comparator. It shows that only the annulus A occupies the outer portion of the photometric field. First $P+V$, the practical task and the veil-

ing luminance, and then $S+\widetilde{\Delta}S+V$, the standard background, the standard target and the veiling luminance occupy the central portion of the photometric field.)

At the outset, it was not apparent to what extent it would be preferable to adjust the contrast or the size of the standard disc target to reach the visibility threshold. Accordingly, provisions were made for both means of adjustment. The size of the standard disc target was varied by a telescopic zoomar system, based upon two lenses whose position with respect to an aperture, and whose positions with respect to each other, could be varied mechanically so as to provide continuous variation in magnification without loss of focus. The telescopic zoomar system performed satisfactorily.

An evaluation was made of the relative precision of determining equivalent standard discs by varying size or contrast. Seven observers were used, each of whom made 10 settings with each system. The percentage errors were slightly smaller when contrast, rather than size, was varied. Of course, the variable contrast device is considerably simpler and requires less care in use. For these and other reasons, it was decided to adopt a procedure of varying contrast rather than size. It was arbitrarily decided to adopt a four-minute luminous disc as the target of standard size, and to vary the contrast of this disc to establish equivalence with various practical tasks.

Once an equivalence has been established between a given practical visual task and a standard luminous disc target with the VTE, it is possible to establish the lighting required to provide a criterion amount of visual performance, utilizing a standard curve representing the desired level of visual performance of the four-minute luminous disc target. The next section will describe the development of a standard visual performance curve for this purpose.

V. Standard Visual Performance Curve

As is indicated in Section IV, we require a standard visual performance curve representing a level of visual performance to be provided for various visual tasks by the use of suitable lighting levels. It is to be emphasized that the standard performance curve to be developed is recommended for current use, based upon our current knowledge of visual performance. Subsequent information may lead in time to other standard performance curves, as is suggested in Section VIII. It should be remembered that the method being described in this report is considerably more general than any specific standard performance curve recommended at a particular time.

In developing a standard performance curve, we must first decide upon the units in which performance should be described. It was decided on the basis of experiments described in Section IV that the contrast of the standard target would be varied in the process of determining equivalence between various practical tasks and the standard luminous disc target. Accordingly, the standard performance curve should represent the functional relation between target contrast and background luminance. Thus, the standard performance curve will be analogous to the performance curves presented in Figs. 8-12, in which each curve represents a fixed level of visibility, specified by an accuracy level of 50 per cent at threshold, and by a level of visual capacity implied by the exposure duration of the target. We need to select a suitable level of visual capacity, a suitable level of accuracy, and a suitable field factor. The general discussion of the previous sections provides the basis for the selection of these constants.

The analysis of the basic characteristics of visual information assimilation presented in Section I has suggested the desirability of insuring that information assimilation can occur within a single fixational pause. To insure this level of performance we must provide a level of visual capacity sufficient to permit assimilation of at least five items of information per second. A level of five assimilations per second (5 APS) does not appear to be nearly the upper limit of visual capacity. As indicated in Section I, studies of visual performance for multiple items presented successively at one point in the visual field, and of multiple items presented simultaneously at different points in the visual field, suggest that a visual capacity of at least 30 APS is possible. Nonetheless, it was decided that the standard performance curve to be used at the present time should be based upon only a 5 APS level of visual capacity. Selection of this level is surely conservative, since it provides the capacity to assimilate only a single item of information per fixational pause. It is perhaps wise to be conservative at this time since the proposed method is new and we have had no experience with its use. Furthermore, we cannot claim that we fully understand, at present, the visual capacity to assimilate multiple items of information in a fixational pause. The experiments we have conducted are limited to instances in which the multiple items either reinforced each other (the Clark experiment) or at least did not contradict one another (the Harcum experiment). There will surely be instances in which multiple items of information which should be assimilated within a fixational pause will interfere with each other. We require considerable fur-

ther study of the assimilation of multiple items of information within a fixational pause before we can begin to utilize standard performance curves based upon visual capacity levels in the range from 5-30 APS.

It is probable that ultimately we will have to recognize that different levels of visual capacity should be provided for different visual tasks. This concept is considered in some detail in Section VIII, and the basic groundwork is established for development of the lighting specification method in this direction once we have a solid factual basis upon which to proceed. For the present, it seems wise to base our standard performance curve upon a level of visual capacity which is surely the minimum required for all visual tasks.

As we noted in Sections II and III, it would scarcely be suitable to establish a 50 per cent accuracy level under conditions of laboratory seeing as the standard level of visual performance. Instead, we wish to use an accuracy level of 99 per cent, and a field factor to represent the conditions of everyday seeing.

In both the 1952[1] and the 1955[2] papers, the method of converting the performance data from one level of accuracy to another was described. We can allow for a change, for example, from 50 per cent to 99 per cent accuracy by multiplying the values of threshold contrast on a particular graph by a constant multiplier. The multiplier varies with exposure duration. For $^1/_3$-second exposures the multiplier is 2.05, whereas for $^1/_{10}$-second exposures the multiplier is 1.87. A multiplier for use with the $^1/_5$-second data, which represent the 5 APS level of visual capacity, was determined by linear interpolation on a logarithmic scale of exposure duration. A value of 1.98 was obtained for the multiplier.

The discussion of field factors presented in Section III above suggests that different visual tasks may well require different field factors, due to differences in the amount of sensory guidance required by the oculomotor adjustment functions and differences in the amount of knowledge the observer will have concerning the nature of the visual task. This concept is considered at some length in Section VIII. Of course, we have no factual basis at the present time for assigning different field factors to various tasks. It seems proper, therefore, to use a single field factor for all tasks until we have a defensible procedure to use in assigning field factors to different tasks.

It was decided that a field factor of 15 would be recommended for use at the present time. In selecting FF 15 as the one value for use with all tasks, heavy reliance was placed upon the fact that the assessment of the field factor in the Field Task Simulator resulted in values of FF between 15 and 18.1. Thus, selection of FF 15 was considered conservative on the basis of the only actual field determination of a field factor we had. In terms of the analysis presented in Section III, selection of FF 15 means that we are providing for a four-degree receptive field, and for a moderate loss in information concerning the visual task. Based upon our analysis of field factors, we might conclude that FF 15 is somewhat large for tasks in which either a smaller receptive field than four degrees is required, or in which there is very little loss in information. On the other hand, FF 15 is probably somewhat small for tasks in which either a larger receptive field than four degrees is required, or in which there is a considerable loss in information. Thus, from the point of view of the analysis of field factors, FF 15 may be considered generally representative of all tasks. It must be emphasized, of course, that at the present time heavy reliance cannot be placed upon the analysis of field factors. The only actual determination of a field factor we have comes from the Field Task Simulator study. As indicated above, a value of 15 is the lower limit of the range of values obtained in this study. Thus, selection of a field factor of 15 must be considered a conservative estimate on the basis of our present knowledge.

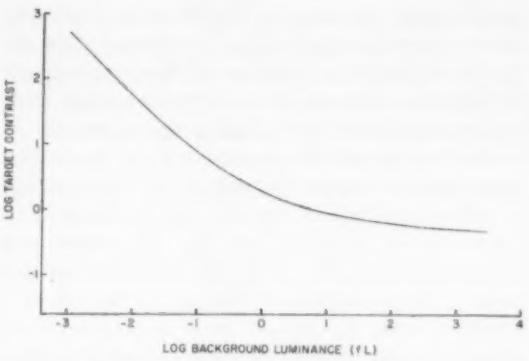

Figure 23. Standard visual performance curve based upon a four-minute standard disc target for a visual capacity level of five assimilations per second (APS). The field factor is 15; accuracy is 99 per cent.

The standard performance curve for the 5 APS level of visual capacity, adjusted to 99 per cent accuracy and to FF 15, is presented in Fig. 23. It is recommended that this curve be used for the current specification of lighting levels for various visual tasks. This curve was constructed from a threshold curve for a $^1/_5$-second exposure duration obtained in the following way. First, values of threshold contrast were obtained for various lumi-

level at which the contrast of the standard disc

Inspection of the construction of Fig. 24 reveals

nance levels up to 100 footlamberts from the smooth curves of the original laboratory data described in Section II. Values of threshold contrast for higher luminance levels were computed from values of relative threshold contrast values at various luminance levels, obtained in the recent experiments reported in Section II. These values of relative threshold contrast were obtained by linear interpolation between the values presented in Tables II and III, when exposure duration was plotted on a logarithmic scale. (A quantitative description of the method used to construct the threshold curve for $^1/_5$-second is contained in Section VIII, and the actual threshold curve is exhibited in Fig. 33, which will be described later.)

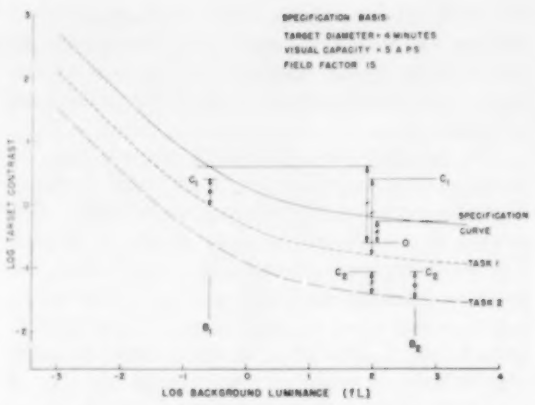

Figure 24. Illustration of the operating principles of lighting specification system. Explanation in text.

VI. The Lighting Specification Procedure

Now that we have described the operation of the Visual Task Evaluator and have developed the standard performance curve, it will be possible to describe the entire lighting specification system. Fig. 24 represents the operation of the specification system graphically, utilizing the standard performance curve developed in Section V, presented in the figure as the solid curve. Now, let us suppose that we have two practical tasks to be evaluated. In our example, we assume that we have advance knowledge of the threshold performance curves for these tasks, so as to illustrate the procedures and assumptions of the method. We assume that if we reduced the over-all contrast of these tasks, the relation between threshold contrast and the over-all luminance would be identical in form to that actually found by measurement with the four-minute standard disc target. That is, the threshold performance curves for Tasks 1 and 2, shown in Fig. 24, are parallel to the standard performance curve, which is itself constructed parallel to the threshold curve for a four-minute disc presented for $^1/_5$-second duration.

Now, let us suppose that we evaluate Tasks 1 and 2 with the VTE at an arbitrarily chosen level of luminance equal to 100 footlamberts. We assume that the actual contrast of Task 1, before reduction by the wedge in the VTE is of the value C_1, represented by a horizontal line drawn at a real value of log target contrast. The reduction of contrast of Task 1 to the visibility threshold is represented in the figure by the arrow with a single crossmark, extending down from the line C_1 to intersection with the threshold performance curve of Task 1, which is the upper dashed curve. Note that this line is drawn vertically over the value of log background luminance = 2, corresponding to 100 footlamberts. The length of the arrow represents the amount of contrast reduction which must be introduced by the contrast wedge; it corresponds to the degree of rotation of the wedge. The second operation in the VTE involves determining the value of initial contrast of the standard four-minute disc which is also at threshold visibility when the contrast wedge is left untouched after the setting made to reduce Task 1 to threshold. The contrast value labeled 0 is intended to represent the threshold contrast of the observer for a four-minute target with a 100-footlambert background luminance under the conditions of setting the VTE. (This value will normally fall below the standard performance curve because time is virtually unlimited in the VTE measurements.) The operation of adjusting the initial contrast of the four-minute disc until it is at threshold when viewed through the contrast wedge therefore involves moving up from the point 0 a distance on the log target contrast scale equal to the distance moved down in reducing the contrast of Task 1 to threshold. The literal accuracy of this statement is apparent if it is remembered that a fixed distance on the log contrast scale is equivalent to a fixed percentage contrast change, which is precisely what a given setting of the contrast wedge provides to all tasks. Thus, the other single-marked arrow measuring up from the contrast level 0 reaches to a value of initial contrast which is the contrast for the four-minute standard target equivalent to Task 1. (This arrow should, of course, also be constructed along a vertical line representing log background luminance = 2, since the setting of the standard disc target is extending down from the line C_1 to intersect with the threshold performance curve of Task 1, For ease of construction, the arrow was arbitrarily displaced to the left of the first arrow.)

The lighting specification system proceeds by defining the level of luminance for Task 1 as the

level at which the contrast of the standard disc equivalent to Task 1 will fall on the standard performance curve. Thus, the operation involves extending a horizontal line from the head of the second single-marked arrow until it intersects the standard performance curve. The specified luminance level for Task 1 is B_1 which is shown in the figure to be a level between .1 and 1 footlambert.

We may well inquire to what extent this level of luminance will provide more task contrast than required for threshold visibility. The extent to which the threshold contrast is less than the value C_1 measures the extent to which our specification system has resulted in a condition of supra-threshold visibility for the task. The arrow with the central black dot located above the luminance B_1 measures the distance from the threshold contrast for Task 1 at luminance B_1 to the actual contrast C_1. Since this measures a distance on the log target contrast scale, the length of this arrow measures the supra-threshold visibility factor of 2.51.

Consider next the case of Task 2. The lower dashed curve is the threshold performance curve and the actual task contrast is represented by the level C_2. As before, the VTE evaluation is assumed to have occurred at 100 footlamberts background luminance. The double-marked arrow represents the extent of reduction in task contrast required to bring Task 2 to threshold visibility. As before, the operation of setting the contrast of the standard disc target involves moving up on the log contrast scale from the contrast value 0 a distance equal to the distance the value of C_2 had to be reduced to bring it to threshold. The double-marked arrow constructed upwards from 0 represents this operation. (This arrow should also be constructed vertically along the log background luminance scale at 2, but it was moved arbitrarily to the right to avoid confusion.) The value of contrast corresponding to the top of this arrow represents the contrast of the standard disc corresponding to Task 2. This value of contrast is continued across horizontally until it intersects the standard performance curve. The luminance corresponding to this point of intersection is labeled B_2; it represents the luminance level at which Task 2 should be performed to provide the supra-threshold level built into our standard performance curve. As before, the extent to which luminance B_2 will provide a supra-threshold level of performance for Task 2 is measured by the extent to which C_2 exceeds the threshold for Task 2 at luminance B_2. This extent is measured by the arrow with the central black dot located above luminance level B_2. The length of this arrow indicates that Task 2 will also have a supra-threshold visibility factor of 2.51 at luminance B_2.

Inspection of the construction of Fig. 24 reveals that this system will always result in supra-threshold visibility factors which are equal so long as the threshold curves for various tasks are parallel to the standard performance curve. The placement of the threshold curves on the log contrast scale, and the initial contrast values of the tasks do not alter the supra-threshold factor obtained for all tasks. The absolute placement of the standard performance curve alters the luminances specified, and the magnitude of the supra-threshold factor obtained for all tasks. Obviously, the higher the standard performance curve on the log contrast scale, the greater will be the supra-threshold visibility factor for all tasks.

The level of the observer's threshold for the standard disc also affects the luminances specified and the supra-threshold visibility factor obtained, if this quantity varies while the thresholds for Tasks 1 and 2 do not vary. The null-comparison method adopted as the standard procedure in the VTE was intended to minimize this possibility, since the thresholds for the practical and standard tasks are measured in rapid succession. Actually, this precaution does not appear to be necessary when highly skilled operators are used. It is possible to compare settings made on the standard disc in the VTE at various times, by plotting the contrast values $B_{\Delta S/B_S}$ as a function of the setting of the variable contrast wedge. It has been found that data collected in different observing sessions separated by months were in very good agreement, provided the VTE measurements were made at the same luminance level. The setting of the annulus provides a means of establishing the average luminance at which the VTE measurements are made. If the measurements are made at different luminance levels, the operator's threshold for the standard discs will, of course, be different. Use of the null-comparison method cancels out this variable. It should be apparent from the construction of Fig. 24 that the luminance level at which the VTE measurements are made does not affect the result obtained, provided the threshold contrast curve of the operator for the standard disc target is parallel to the standard performance curve. As suggested by the above discussion, it is convenient to make all VTE measurements at a single luminance level, since it is possible to pool the data obtained on various settings of the standard targets to increase the precision of each individual equivalence setting.

There is, however, a separate argument which suggests that it would be preferable to evaluate various tasks at luminance levels near the ones which will be eventually specified. The errors introduced in the specification process due to non-

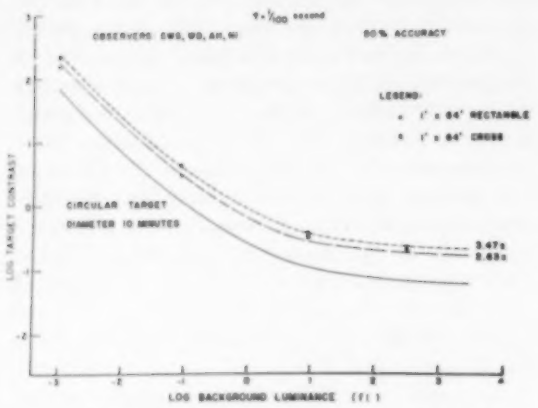

Figure 25. Threshold contrast data for a rectangle and a cross target presented for a 1/100-second duration. The solid curve represents a threshold curve interpolated from the basic laboratory data. The dashed curves represent laboratory contrast values multiplied by factors of 2.63 and 3.47, respectively.

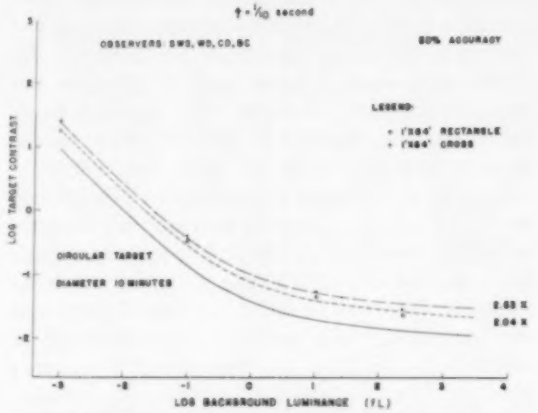

Figure 26. Threshold contrast data for a rectangle and a cross target presented for a 1/10-second duration. The solid curve represents a threshold curve interpolated from the basic laboratory data. The dashed curves represent laboratory contrast values multiplied by factors of 2.04 and 2.53, respectively.

parallelism of the threshold curves for various tasks will be minimized if the assessment of each task is made at a luminance level near the value which ends by being specified. This argument may suggest the use of an iterative procedure for arriving at the final lighting specification.

We well may wonder to what extent the threshold performance curves for various tasks are parallel to one another. During 1956-1957, Stanley W. Smith of the University of Michigan staff studied threshold curves for two tasks which were selected to be markedly different from the luminous disc used as the standard target. One target was a long thin rectangle, subtending 1 minute by 64 minutes. The other target was a 90-degree cross made from two 1-minute by 64-minute rectangles. The apparatus and procedures were identical with those of the main laboratory studies reported in Section II. Groups of four observers were used for each target, at each of the three exposure durations: 1, $^1/_{10}$, and $^1/_{100}$ second. Measurements were made in each case to define the functional relation between log threshold contrast and log background luminance, for comparison with the functional relations obtained with circular targets of equal area. The results for the $^1/_{100}$-second exposure duration are presented in Fig. 25. The solid curve is for a circular disc with a 10-minute diameter. The results for the rectangle and the cross are shown as data points. The two dashed curves represent the solid curve adjusted with respect to the contrast scale so as to provide the best fit to the data for each target. The contrast multiplier used to adjust the curve is indicated in each case. The curves in each case fit the data points well, revealing that the threshold curve has very much the same shape for the non-circular and circular targets viewed at an exposure duration of $^1/_{100}$ second.

Similar data for the $^1/_{10}$-second exposure duration are presented in Fig. 26. As before, the solid curve is for a disc target and the dashed lines represent the curve for the circular target adjusted so as to best fit the data on the rectangle and the cross targets. The curve fit seems quite adequate for the rectangle target. The data point obtained with the cross target at the highest luminance falls well below the upper dashed curve, suggesting that there may be a difference in the functional relation between threshold contrast and background luminance in this case.

The data for 1-second exposure duration are presented in Fig. 27. In this case, the curves fitted through the data points for the rectangle target fit the curve derived from the disc target fairly well, but the data points for the cross target depart markedly from the curve fitted to them. Clearly, the functional relation between threshold contrast and background luminance is different for the cross target and disc target of equal area.

Of course, an examination of the curves which are shown in Figs. 8-12 reveals differences in the functional relation between threshold contrast and background luminance as great as these differences, when disc targets are varied in size over a large range. These data make it clear that there will be errors introduced into the lighting specification method due to non-parallelism of the threshold curves obtained with various visual tasks. However, in a broad sense, the threshold curves bear great resemblance to each other. As indicated

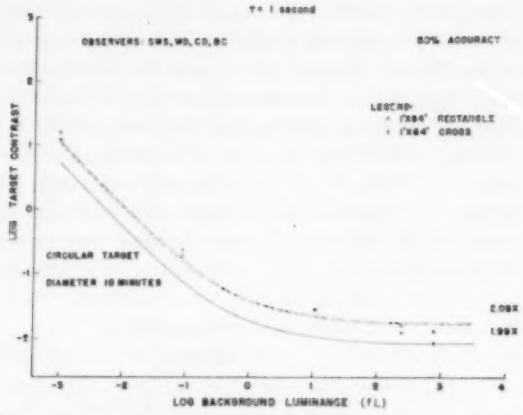

Figure 27. Threshold contrast data for a rectangle and a cross target presented for a one-second duration. The solid curve represents a threshold curve interpolated from the basic laboratory data. The dashed curves represent laboratory contrast values multiplied by factors of 1.99 and 2.09, respectively.

above, differences in the form of these curves can be minimized by evaluating each task at a luminance level as close as possible to the one specified by the system.

It is worth noting that our selection of a four-minute standard disc, rather than a one- or 60-minute disc target, serves to minimize the effect of non-parallelism of the threshold curves, since the curve for the four-minute disc is of roughly intermediate form with respect to those shown in Figs. 8-12 and in Figs. 25-27.

The above account completes our description of the lighting specification process as it is recommended that it be utilized currently. Before reporting the lighting levels recommended for a sample of practical visual tasks, it will be well to discuss two general problems concerned with this method. The first of these concerns the application of the method to visual tasks for which there is luminance non-uniformity in the visual field. The second concerns the applicability of the performance data reported here to the population as a whole.

Application of the Method to Visual Tasks Involving Luminance Non-Uniformity In the Visual Field

It is important to indicate to what extent the present method of specifying lighting levels assumes that the visual field of practical tasks is uniform in luminance. It should be emphasized that the laboratory studies on disc targets were conducted with extended fields of uniform luminance, as were the studies in the Field Task Simulator and the analytical studies of field factors. Thus, the standard performance curves presented in Fig. 23 represent extended fields of uniform luminance.

The VTE has an inner photometric field whose diameter is 2.3 degrees. Thus, when the operator evaluates the difficulty of a practical visual task, luminance non-uniformity of the background in the vicinity of the task influences the task difficulty as it would in actual performance of the task. When the standard disc is viewed within the VTE, it is presented on a field of uniform luminance. Determination of the value of the equivalent contrast of each task thus takes full account of luminance non-uniformities in the vicinity of the practical task, and correctly relates each task to the standard performance curve for the four-minute disc, based upon fields of uniform luminance.

If there are areas in the surround of the task of higher luminance than the task and its immediate background, the task will be more difficult than the VTE measurement indicates it to be, due to the effect of disability glare. Furthermore, the presence of areas in the surround having lower luminance than the task and its immediate background will probably make the task more difficult than the VTE measurement indicates, due to transient adaptational effects. We do not have at present any quantitative method of dealing with the transient adaptational effects, but we do have a quantitative method for dealing with the disability glare effect.

The method of allowing for the deleterious effects of disability glare was described in principle in the author's 1955 article.[2] It was shown that curves relating log contrast and log background luminance can be generated to represent various ratios between the veiling luminance produced by all the sources of disability glare in the surround, and the luminance of the task and its immediate background. Curves representing different ratios between these quantities may be generated from the standard performance curve presented in Fig. 23, using the method described in the earlier article. Once these curves are available, we require a method of establishing the value of veiling luminance actually produced by the surround of a given task. It is possible for the veiling luminance to be computed from the familiar disability glare formulation of Moon and Spencer,[21] provided a considerable number of photometric measurements are made first. A much simpler procedure involves use of the proposed Fry Disability Glare Meter,[22] which yields direct values of the ratio of the veiling luminance to the luminance of the task and its immediate background. These ratios may be used with the new families of performance curves, to

compute lighting levels to be used when there is an appreciable amount of disability glare.

Non-uniformity of the distant surround of the task will also alter the difficulty of many visual tasks, due to reflected glare. This effect is properly assessed by the present method if the VTE measurements are made with the task in its realistic environment. As will be reported in Section VII, our measurements of sample visual tasks were made in the laboratory with simple directional illumination which was shown to be generally equivalent to completely diffuse illumination. Thus, the light levels specified in the present paper assume the absence of reflected glare as well as the absence of disability glare. Recent measurements by Finch[23] and by Chorlton and Davidson[24] reveal the presence of considerable losses in task contrast when the tasks are measured under actual room conditions. These results imply that the tasks are considerably more difficult than our measurements indicate, due to the effects of reflected glare. If reflected glare cannot be eliminated, considerably more lighting must be utilized than is indicated in the present paper, to compensate for its deleterious effects. The extent to which a reduction in task contrast by reflected glare will increase the required lighting may be determined directly from the performance curve presented in Fig. 23. The slope of this curve, on the log-log plots, indicates directly the percentage increase in luminance, and hence illumination, required to compensate for a one per cent decrease in task contrast due to reflected glare. It is apparent that the performance curve becomes flatter at higher luminances. This means that greater percentage increases in lighting are required to compensate for a one per cent loss in task contrast, the higher the initial level of lighting.

Sample calculations will prove revealing. Assume, based upon the Chorlton and Davidson study, that a 13 per cent contrast reduction can often occur due to reflected glare in actual classrooms. The standard performance curve presented in Fig. 23 may be used to compute the illumination levels required to compensate for this contrast loss. For the purposes of these calculations, a task reflectance of 0.70 was assumed. The results are presented in Table V. It is apparent that large increases in illumination are required to compensate for a 13 per cent loss in task contrast due to reflected glare.

TABLE V — Illumination Levels Required to Compensate for a 13 Per Cent Loss in Task Contrast Due to Reflected Glare.

Glare-free Illumination	Illumination Needed in the Presence of Reflected Glare
(Footcandles)	(Footcandles)
10.	18.9
20.	45.2
30.	73.5
40.	101.
50.	140.
60.	193.
70.	202.
80.	238.
90.	286.
100.	299.

Comments on the Population Sample Involved in the Present Researches

It should be apparent from the descriptions of the experiments given above that only a few observers were used. The major part of the basic laboratory data depend primarily, in fact, upon only two observers. We may well wonder to what extent these observers represent the population as a whole. It must be emphasized at once that these observers do not at all represent the population as a whole; they were selected to represent the best possible visual performance to be found. These two observers, and the others used throughout the present study, were young adults in the age range from 18-32 years. They were all examined ophthalmologically and were known to have excellent sensory and oculomotor functions of every sort. Those observers needing slight refractive corrections were provided with the corrections during the experiments. All observers were intelligent enough to be successful as university undergraduate or graduate students, and all were well motivated.

Under these circumstances, the data reported here may reasonably be supposed to represent optimal performance. Presumably, older and younger observers may be expected to perform less well, as will most persons with mild or severe ocular deficiencies, as well as persons with less intelligence and motivation than our observers. Presumably, higher lighting levels will be required for the less-than-optimal performance to be expected from the bulk of the population. Extensive further experiments will be required to establish quantitative lighting needs for various segments of the population differing from our observers in the ways indicated. It is hoped that these experiments will in fact be conducted in the next few years.

VII. Evaluation of Practical Visual Tasks

During January of 1958, various technical committees of the IES selected what they considered important visual tasks encountered in various everyday activities and sent them to the Univer-

sity of Michigan for evaluation and computation of lighting specifications for them, based upon the quantitative method described above. In our evaluation of the tasks, we mounted them in front of the VTE as shown in Fig. 21. We arbitrarily decided to illuminate each ordinary task with the 35 mm slide projector shown in the figure, with the illumination striking the tasks at 45 degrees from normal to their surfaces. This illumination method was intended to eliminate specular reflection. There were a few tasks which are normally seen by specular reflection; for these a specular highlight was deliberately provided. In most cases, the illumination was adjusted to provide a background luminance of 100 footlamberts in order to increase the precision of measurements by making it possible to pool all measurements made on the standard disc targets.

Initially VTE readings were made by three trained photometrists and illumination specialists: Benjamin S. Pritchard of the University of Michigan staff; Arthur A. Eastman of General Electric Co., Nela Park; and C. L. Crouch, Technical Director of IES. Fourteen tasks were evaluated by all three operators. Operator Pritchard was found to give readings on the average less than two per cent different from the grand average obtained on all three operators. In order to simplify subsequent data collection, studies on the remaining 42 tasks were made by Pritchard alone. Pritchard's data are used for the tasks he alone measured; the average data for the three operators were utilized for the fourteen tasks studied by all three. The basic result in every case is a value of the contrast of the four-minute standard disc target of difficulty equivalent to the task. These values, known as equivalent contrasts and symbolized by $\tilde{C}$, may be utilized directly with the standard performance curve of Fig. 23 to compute luminance levels for the desired performance criteria. From reflectance measurements made at the time of evaluation, illumination levels may be computed.

Before presenting the data, it will be well to report a supplementary study carried out to ascertain to what extent the measurements obtained with the projector were equivalent to results obtained under fully diffuse illumination. A hemisphere was constructed from half of a 12-inch world globe, and coated inside with magnesium oxide. A shielded source of light was added. Measurements were made with the VTE under this condition of illumination for comparison with measurements made under 45-degree directional illumination with the projector. The samples that were studied represented type, pencil, and ink writing on matte paper. The contrast values obtained with diffuse illumination were divided by the corresponding values obtained with the 45-degree diffuse illumination. The average ratio was 1.01, suggesting that at least "non-specular" tasks, such as those selected for study, yielded equivalent values under the two types of illumination.

Footcandle values assigned on the basis of the presently recommended standard performance system are presented in Table VI. This system, and these values, were utilized by the IES Committee for Recommendations of Quality and Quantity of Illumination in preparing their report of the present research to the IES Technical Committees.[20]

In May 1958, the Joint Committee on School Lighting submitted a number of samples of schoolroom visual tasks for assessment on the VTE. Nineteen samples of spirit-duplicated material were made available from Massachusetts schools, as were five samples from Michigan schools. Since these samples all represent work sheets and are very much alike, it does not seem necessary to present the results obtained with each sample. The samples were graded in difficulty into two categories, with values of log equivalent contrast equal to .185 and −.215, respectively. Using the currently recommended standard performance curve, footcandle values of 2.14 and 141. were obtained for the 12 easy tasks and the 12 more difficult tasks.

There is, of course, no simple way to evaluate the accuracy of the lighting recommendations made with this system. At least for the present, it may have to suffice to evaluate to what extent these lighting values agree with our total experience with various visual tasks. The adequacy of low footcandle levels for reading high contrast print certainly agrees with some evidence of the illumination needs of this task. The need for very high illumination levels for certain very difficult garment and textile tasks certainly agrees with our experience of wanting to take these tasks to the window or out-of-doors. The present data should stimulate considerable careful assessment of accumulated experience with various visual tasks.

A method for checking the internal consistency of the system, suggested by S. K. Guth and A. A. Eastman, has been investigated. This suggestion involves determining the equivalent contrast for the standard four-minute disc for each of a number of non-specular tasks, then using a performance curve, such as the one presented in Fig. 23, to establish illumination levels for all these tasks. The next step involves illuminating each task to the level specified in this way. If the method is internally consistent, it should now be possible to show that

TABLE VI — Values of Illumination or Luminance for 99 Per Cent Accuracy.
Field Factor 15 Visual Capacity 5 APS

Task No.	Task Description	Log $\tilde{C}$	R	E (fc)	B (fL)
1.	Reading while writing: sample of ink-writing, one 6th grade student	.273	.76	1.38	
2.	Reading while writing: samples of No. 2 pencil writing, twelve 6th grade students with poorest writing in class of 31	−.167	.76	63.0	
3.	Reading: 8-point Bodoni type	.228	.70	1.87	
4.	Reading: 6-point textype	.144	.70	2.98	
5.	Reading: 8-point textype	.333	.70	1.13	
6.	Reading: 10-point textype	.372	.70	0.94	
7.	Reading: 12-point textype	.478	.70	0.60	
8.	Reading while transcribing: sample of shorthand copy with No. 3 pencil	−.181	.79	76.5	
9.	Reading: typed original, good ribbon	.397	.62	0.97	
10.	Reading: typed original, extremely poor ribbon	−.338	.62	3140.	
11.	Reading: typed carbon, fifth copy	−.194	.53	133.	
12.	Reading: dark blue mimeograph stencil, with clear plastic overlay	.498	.11	3.54	
13.	Reading: Thermofax copy, poor quality	−.278	.63	589.	
14.	Reading: No. 2 pencil on tracing paper over blueprint	.050	.59	6.58	
15.	Cutting: white chalk mark on blue serge cloth	.664	.020	10.4	
16.	Inspection: dot defects on dark blue cloth	.562	.017	17.8	
17.	Inspection: gray line defect on black cloth	.369	.024	27.5	
18.	Inspection: darned blemish on gray cloth	−.022	.10	74.1	
19.	Inspection: brown stitching on brown silk		.12		
	a. vertical stitching	−.398		>10000.	
	b. horizontal stitching	−.022		61.7	
20.	Inspection: gray stitching on gray silk		.076		
	a. vertical stitching	−.268		4160.	
	b. horizontal stitching	−.468		>10000.	
21.	Cutting: orange chalk on light brown tweed	−.168	.18	266.	
22.	Cutting: white chalk on gray cloth	−.018	.33	21.0	
23.	Inspection: light stitching on blue serge cloth		.018		
	a. vertical stitching	.915		5.05	
	b. horizontal stitching	1.191		2.22	
24.	Inspection: pattern threads, men's silk and wool suiting	−.021	.22	32.9	
25.	Inspection: dark brown raised threads on silk	−.180	.035	1680.	
26.	Inspection: blue-gray raised threads on silk	−.283	.046	9650.	
27.	Inspection: pattern threads, white handkerchief	−.045	.91	9.86	
28.	Inspection: pocket stitching, tan shirt	−.318	.53	1890.	
29.	Reading: price tag, pencil	−.236	.63	241.	
30.	Reading: price tag, ink	.127	.76	3.10	
31.	Inspection: broken white wool thread on spinner bobbin		.66		
	a. 30° illumination	.302		1.26	
	b. normal illumination	.042		6.32	
32.	Inspection: broken black thread on spinner bobbin, 30° illumination	−.174	.018	2920.	
33.	Inspection: broken gray thread on spinner bobbin, 30° illumination	.295	.079	11.8	
34.	Inspection: broken white nylon thread on spinner bobbin, 30° illumination	−.279	.78	487.	
35.	Inspection: skip defect, viewed from 16 feet	−.080	.19	71.0	
36.	Inspection: tight sound edge knot, viewed from 16 feet	.121	.19	12.9	
37.	Inspection: bark wave, viewed from 16 feet	−.193	.19	381.	
38.	Inspection: small decay spot, viewed from 16 feet	−.443	.19	>10000.	
39.	Inspection: chip grain, viewed from 16 feet	−.323	.19	6470.	
40.	Inspection: small seasoning check, viewed from 30 inches	−.181	.19	317.	
41.	Inspection: small skip defect, viewed from 30 inches	−.148	.19	187.	
42.	Inspection: chip grain, viewed from 30 inches		.19		
	a. no specular	−.243		1030.	
	b. specular	.114		13.4	
43.	Inspection: brown color difference in cloth	−.211	.12	870.	
44.	Reading: proofed type	−.442			>3160.
45.	Reading: unproofed type	−.283			447.
46.	Reading: vernier calipers, non-etched	−.300			631.
47.	Reading: new micrometer, etched	−.022			7.41
48.	Reading: old micrometer				
	a. specular on numbers	−.233			148.
	b. specular on division	.030			4.62
49.	Reading: white line on blueprint, tracing paper overlay	−.558	.59	>5090.	
50.	Inspection: brown thread stitching on brown silk tweed	−.593	.12	>10000.	
51.	Cutting: white chalk on tan cloth	−.561	.24	>10000.	
52.	Inspection: rolled-edge defect on white handkerchief	−.725	.91	>3470.	
53.	Inspection: seasoning check, viewed at 16 feet	−.545	.19	>10000.	
54.	Inspection: brown stain on gray cloth	−.523	.12	>10000.	
55.	Inspection: brown spot on red necktie	−.545	.084	>10000.	
56.	Inspection: brown spot on tan necktie	−.694	.18	>10000.	

each task has an equal supra-threshold visibility level. This condition may be readily evaluated by reducing each of the specially illuminated tasks to threshold, using the amount of contrast reduction required to bring each task to threshold as a measure of supra-threshold visibility.

This check of internal consistency was conducted for illumination levels based upon the present system for tasks Nos. 4, 7, 8, 9, 11, 29 and 30. The predictions of illumination levels were based upon the performance curve for 7 APS. (The performance curve used is of no importance to this check except insofar as the various performance curves differ in shape from one to another. The curve for 7 APS, in fact, appears very similar in shape to the standard performance curve of Fig. 23.) The supra-threshold visibility factors for the seven tasks were averaged and the ratio of the factor obtained with each task to the average was computed. These ratios give a direct measure of the extent to which predicted illumination levels from the lighting specification system resulted in equivalent supra-threshold visibility factors for the various tasks. The ratios for the seven tasks were, in order: .94, .97, 1.03, .90, 1.00, 1.04, and 1.13. The average departure from a ratio of 1.00 was only .05, an average deviation of only five per cent. It is to be emphasized that the illumination levels specified for the various tasks varied from .4 to 339 footcandles. This evaluation certainly suggests that the standard lighting specification system has internal consistency. It suggests that the threshold performance curves for the seven tasks must be essentially parallel to that for the standard four-minute disc, presented for $^1/_7$ second.

VIII. Future Developments of the Method

As indicated in Section VI, it is recommended that the lighting specification system for current use should be based upon a level of visual capacity of 5 APS and a field factor of 15 for all visual tasks. These performance criteria represent conservative estimates for current use, based upon our best current knowledge of visual performance. However, it was also pointed out in Section VI that it is entirely likely that different visual tasks actually require different levels of visual capacity, and that the conditions under which these tasks are performed suggest that different field factors should be used when specifying lighting levels for the various tasks. Of course, at present, there is no satisfactory factual basis upon which levels of visual capacity and field factors can be established for different tasks. Considerable further research will be required before it will be possible to make these assignments on a satisfactory basis, and it is hoped that suitable studies will be conducted during the next few years. A lighting specification system in which different levels of visual capacity and different field factors are used for different visual tasks is obviously more complex than the system presently recommended. Its advantage is presumably that this form of application of the lighting specification method will provide lighting levels for individual tasks with greater precision than is possible with the present system. As lighting technology advances, this precision may well be needed.

It seems appropriate to develop, in this report, as many as possible of the basic tools which will be needed to utilize the lighting specification method in this way. Whereas it is not at present possible to describe the procedures to be used in assigning levels of visual capacity and field factors to individual tasks, it is possible to develop the visual performance curves which will be needed for various levels of visual capacity and various field factors. Performance curves for a wide range of levels of visual capacity and a wide range of field factors will be developed. Then, in order to illustrate the procedures to be used with this application of the lighting specification method, lighting levels will be determined for the 56 visual tasks described in Section VII, based upon values of visual capacity and field factors selected by the author as intuitively reasonable.

Obviously, these selections of visual capacity levels and field factors cannot be considered factually established, although all relevant factual material will be used in a general way. Accordingly, the lighting levels specified for the various tasks on this basis cannot be considered factually determined. Nonetheless, it will be instructive to follow through the determination of lighting levels for various tasks. Comparison of the lighting levels obtained in this way and the lighting levels established with the system recommended for current use will provide valuable insights into the general method being used for specifying lighting levels.

Let us begin by constructing visual performance curves for various levels of visual capacity and for various field factors. As in the case of the standard performance curve recommended for current use, we will begin by adjusting our performance data to correspond to 99 per cent accuracy, rather than 50 per cent. As indicated in Section V, this adjustment may be accomplished by the use of contrast multipliers, which are different for different levels of visual capacity. The contrast multipliers to be used for the different capacity levels are obtained from the earliest account of the laboratory per-

TABLE VII — Values of the Contrast Multiplier to Convert from 50 Per Cent to 99 Per Cent Accuracy.

t (Seconds)	Contrast Multiplier	Log Contrast Multiplier
1	2.13	.328
1/2	2.05	.312
1/10	1.87	.272
1/30	1.86	.270
1/100	1.84	.265

formance data.[3] These values are presented in Table VII, for convenience, in terms of the exposure duration of the target. Log factors are presented, since we may allow for the effect of a contrast multiplier by adding the logarithm of this multiplier to each value of log target contrast. This amounts to sliding the contrast scale of graphs like those in Figs. 8-12 by an amount equal to the log factor.

The analytical discussion of field factors contained in Section III provides a basis for determining the range of field factors which may ultimately be needed to describe all visual tasks. In this account, it was argued that a field factor of 2.50, which allows for the criterion difference between laboratory and common sense seeing, would always be needed. It was further argued that the requirements for visual guidance of the ocular adjustment mechanisms of accommodation and vergence would normally necessitate a receptive field extending two degrees in each direction from the fixational center, which requires an additional contrast multiplier of 4.0. Thus, the field factor would be expected to be 10.0, provided the observer has rather complete information concerning the task, and provided the task occurs with reasonable regularity. When knowledge concerning the task is reduced, the field factor would have to be increased. Some reduction in knowledge, whether of the time of occurrence or the location of the task, would presumably increase the field factor to 15.0. Considerable reduction in knowledge would presumably increase the field factor to 20.0.

There may be conditions in which the observer has complete knowledge about the task and may not require an appreciable receptive field because he is able to concentrate on no more than a few objects in the visual field. In these cases, the field factor may be reduced below 10.0 by reducing the factor needed to enlarge the receptive field. A total field factor of 7.5 would represent a factor of 3.0 for enlargement of the receptive field. This would provide a receptive field somewhat greater than 1.5 degrees in every direction from the fixational center. A field factor of only 5.0 would represent a factor of only 2.0 for enlargement of the receptive field, which would give a receptive field measuring approximately 1.25 degrees in all directions from the fixational center. Field factors of 5.0 and 7.5 probably represent values to be expected for tasks in which the usual receptive field is not required.

On the basis of the preceding considerations, it was decided that field factors of 5.0, 7.5, 10, 15 and 20 may be expected to cover the range to be expected for various visual tasks. The threshold curves for the four-minute standard target presented in Figs. 8-12 were adjusted to the 99 per cent accuracy level, and allowance was made for the five field factor values. The contrast multipliers to allow for the accuracy correction were multiplied by the various field factors. The resulting constants were converted into logarithms, which may be applied directly to the threshold curves presented in Figs. 8-12. The factors are summarized in Table VIII.

The visual performance curves obtained by applying these factors to the threshold curves are presented in Figs. 28-32. Each figure presents a family of curves for a given field factor. The various curves are expressed in terms of visual capacity (APS), which is the inverse of the exposure duration in seconds. Note that of the above exposure durations, only the 1-, 1/10- and 1/30-second

TABLE VIII — Values of the Log Factors to Convert from 50 Per Cent to 99 Per Cent Accuracy and to Allow for Various Field Factors (FF).

t (Seconds)	Log Factor FF 5	FF 7.5	FF 10	FF 15	FF 20
1	1.028	1.204	1.329	1.505	1.630
1/2	1.011	1.186	1.312	1.488	1.613
1/10	.971	1.147	1.272	1.448	1.572
1/30	.968	1.144	1.269	1.445	1.570
1/100	.964	1.140	1.265	1.441	1.566

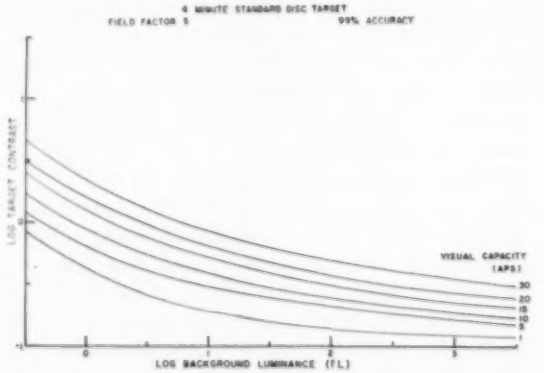

Figure 28. Visual performance curves based upon a four-minute standard disc target. Field factor is 5. Each curve represents a level of visual capacity, indicated in units of assimilations per second (APS).

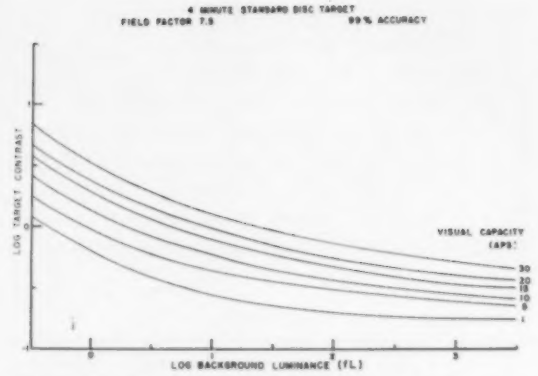

Figure 29. Visual performance curves based upon a four-minute standard disc target. Field factor is 7.5. Each curve represents a level of visual capacity, indicated in units of assimilations per second (APS).

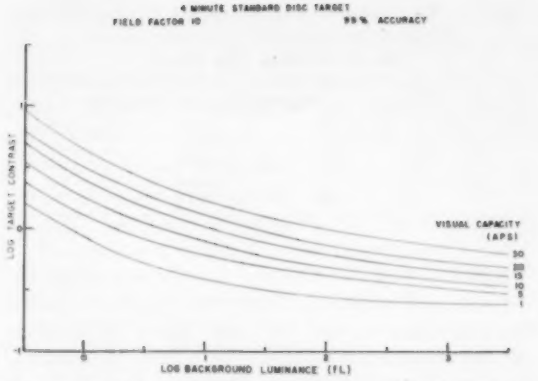

Figure 30. Visual performance curves based upon a four-minute standard disc target. Field factor is 10. Each curve represents a level of visual capacity, indicated in units of assimilations per second (APS).

curves have been utilized. When the curves were being constructed it became apparent that the $^1/_3$-second curve was too similar to the 1-second curve to be worthy of plotting. The $^1/_{100}$-second curve was omitted, since our analysis of visual capacity in Section I suggested that perhaps 30 APS, corresponding to a $^1/_{30}$-second exposure duration, was the maximum level of visual capacity under conditions of normal use of the eyes. The data for the $^1/_{100}$-second exposure duration are presented in this paper so that they will be a matter of record in the event that future investigations reveal the need for levels of visual capacity greater than 30 APS.

In each of the figures, curves representing the additional levels of 5, 15, and 20 APS levels have been included. (The method of deriving these curves will be described in detail subsequently.) The 5 APS level of visual capacity is included because this level corresponds to the capacity to assimilate about one item of information per fixational pause. The 5 APS curve appearing in Fig. 31, representing FF 15, is the curve which is presented earlier in Fig. 23 as the standard performance curve recommended for current use. The 15 and 20 APS levels are included because of the presumed importance of the range of visual capacity between 5 APS, which represents the assimilation of one item of information per fixational pause, and 30 APS, which may well be the maximum level of visual capacity with normal use of the eyes.

In order to construct performance curves corresponding to the 5, 15 and 20 APS levels of visual capacity, it was necessary to obtain corresponding threshold data and conversion factors. Threshold contrast values for a four-minute disc, for exposure durations of $^1/_5$, $^1/_{15}$ and $^1/_{20}$ second were obtained by interpolation from the smooth curves relation log threshold contrast to log exposure duration de-

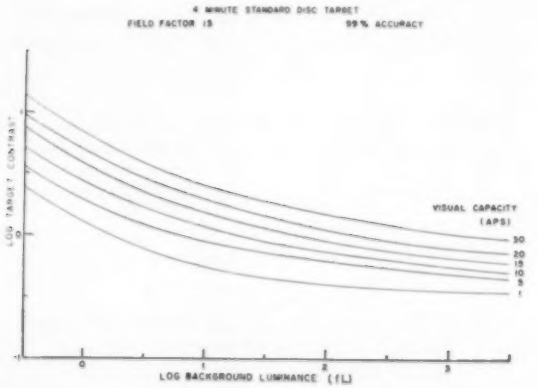

Figure 31. Visual performance curves based upon a four-minute standard disc target. Field factor is 15. Each curve represents a level of visual capacity, indicated in units of assimilations per second (APS).

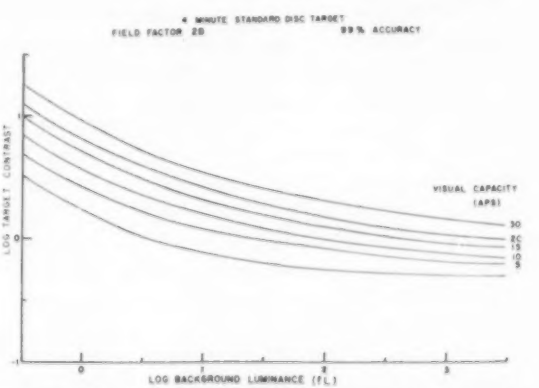

Figure 32. Visual performance curves based upon a four-minute standard disc target. Field factor is 20. Each curve represents a level of visual capacity, indicated in units of assimilations per second (APS).

TABLE IX — Relative Log Threshold Contrast Values for High Background Luminance Levels for a 4-Minute Disc Target.

	Exposure Duration (Seconds)		
Log B (fL)	1/5	1/15	1/20
2.00	.000	.000	.000
2.50	−.060	−.074	−.077
3.00	−.106	−.132	−.138
3.50	−.134	−.172	−.181

veloped during the process of data smoothing described in Section II. These curves were extended to luminances beyond 100 footlamberts on the basis of the recent data obtained at higher luminances. Relative log threshold contrast values were interpolated from the values presented in Tables II and III, with the results shown in Table IX. These resulting threshold data are presented in Fig. 33, together with threshold data for durations of 1, $^1/_{10}$ and $^1/_{30}$ second. It is apparent that the interpolation process resulted in smooth appearing curves of $\dot{C}$ versus B for these exposure durations.

The next step involved determination of contrast multipliers appropriate to correct from 50 to 99 per cent accuracy. Multipliers were interpolated from the values presented in Table VII, with the results shown in Table X. The total log factors needed to convert from 50 to 99 per cent accuracy, and to allow for various field factors, are presented in Table XI. Use of the log factors contained in Table XI permits construction of performance curves for 5, 10, and 15 APS levels of visual capacity. These curves have been plotted in Figs. 28-32, along with the curves for other levels of visual capacity. The families of performance curves contained in these figures will make it possible, at a later date, for different levels of visual capacity and/or different field factors to be utilized in systems of lighting specification.

As noted above, there is no adequate factual basis for assigning levels of visual capacity and field factors to actual practical tasks at this time. However, in order to illustrate the use of the families of performance curves presented in Figs. 28-32, an effort will be made to evaluate the 56 tasks described in Section VI in terms of levels of visual capacity and field factors which *may* be applicable to each task. This evaluation will be intuitive, based upon the general understanding of visual performance which has been developed in preceding sections of this report.

Evaluation of the 56 tasks began with an attempt to estimate a reasonable value of FF to assume in each case. It was decided that the tasks all represented FF 10 and FF 15. All the tasks selected seemed to involve sufficient uncertainty

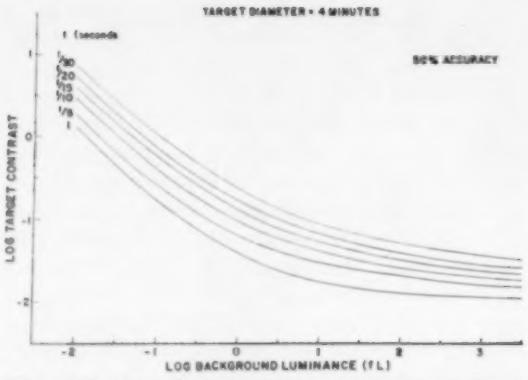

Figure 33. Smoothed threshold contrast curves for a four-minute diameter standard disc target. Each curve represents a different exposure duration in seconds.

as to where the task would appear, or a sufficient need for sensory guidance of the oculomotor adjustment mechanisms so that the enlargement of the receptive field represented by values of the field factor equal to 10 or more was indicated. The tasks where there was complete knowledge of the location of the task, such as reading, were considered to require FF 10. The tasks involving some lack of information as to the exact location or time of occurrence of the task, such as inspection of garments for pattern threads, were considered to require FF 15.

It was assumed that a visual capacity of 30 APS should be provided in each case, unless there were evidence of either information limitation or response limitation in the task. Continuous reading tasks involving no overt response component were considered to be capable of performance at a 30 APS level. However, such tasks as reading while transcribing shorthand were considered to be responses limited to the 15 APS level. Tasks in which there is comparatively little information available, such as reading price tags, were consid-

TABLE X — Values of the Contrast Multiplier to Convert from 50 Per Cent to 99 Per Cent Accuracy.

t (Seconds)	Contrast Multiplier
1/5	1.98
1/15	1.87
1/30	1.86

TABLE XI — Values of the Log Factors to Convert from 50 Per Cent to 99 Per Cent Accuracy and to Allow for Various Field Factors.

t (Seconds)	FF 5	FF 7.5	FF 10	FF 15	FF 20
1/5	.996	1.172	1.297	1.473	1.597
1/15	.970	1.146	1.271	1.447	1.572
1/30	.969	1.145	1.270	1.446	1.571

ered to be information limited to the 15 APS level. Inspection tasks in which there is very little information, such as looking for pocket stitching on a shirt, were considered to be information limited to the 10 APS level. Inspection tasks, such as looking for a broken thread on a spinner bobbin, were considered to be severely information-limited to a level of visual capacity of only 5 APS.

In order to establish lighting levels for each task, the value of log $\widetilde{C}$ for each task was entered on the performance curve representing the estimated level of visual capacity and field factor. A log luminance value was determined for each task. Requisite luminance levels for the specular tasks were obtained directly from these values, whereas requisite illumination levels for the non-specular tasks were obtained by allowing for the task reflectance.

Illumination values for the non-specular tasks,

TABLE XII — Non-Specular Visual Tasks Requiring Field Factor 10. Values of Illumination (Footcandles) for 99 Per Cent Accuracy.

Task No.	Task Description	Log $\widetilde{C}$	R	Visual Capacity (APS) 30	20	15	10	5	1
1.	Reading while writing: sample of ink-writing, one 6th grade student	.273	.76	RL	RL	2.40			
2.	Reading while writing: samples of No. 2 pencil, twelve 6th grade students with poorest writing in class of 31	−.167	.76	RL	RL	69.0	22.4		
3.	Reading: 8-point Bodoni type	.228	.70	*13.7*					
4.	Reading: 6-point textype	.144	.70	*27.8*					
5.	Reading: 8-point textype	.333	.70	*6.70*					
6.	Reading: 10-point textype	.372	.70	*5.38*					
7.	Reading: 12-point textype	.478	.70	*3.12*					
8.	Reading while transcribing: sample of shorthand copy with No. 3 pencil	−.181	.79	RL	RL	*76.4*	23.6		
9.	Reading: typed original, good ribbon	.397	.62	*5.22*					
10.	Reading: typed original, extremely poor ribbon	−.338	.62	*>5100.*	>5100.	1090.	244.	67.3	7.04
11.	Reading: typed carbon, fifth copy	−.194	.53	*3600.*	360.	128.	37.7		
12.	Reading: dark blue mimeograph stencil, with clear plastic overlay	.498	.11	*18.0*					
13.	Reading: Thermofax copy, poor quality	−.278	.63	*>5020.*	1480.	355.	79.5	28.2	
14.	Reading: No. 2 pencil on tracing paper over blueprint	.050	.59	*81.2*	26.2				
15.	Cutting: white chalk mark on blue serge cloth	.664	.020	RL	RL	*17.7*			
21.	Cutting: orange chalk on light brown tweed	−.168	.18	RL	RL	*292.*	92.1	30.6	
22.	Cutting: white chalk on gray cloth	−.018	.33	RL	RL	*38.2*			
29.	Reading: price tag, pencil	−.236	.63	IL	IL	*205.*	47.9		
30.	Reading: price tag, ink	.127	.76	IL	IL	*5.36*			
49.	Reading: white line on blueprint, tracing paper overlay	−.558	.59	IL	IL	*>5360.*	>5360.	>5360.	141.
51.	Cutting: white chalk on tan cloth	−.561	.24	RL	RL	*>10000.*	>10000.	>10000.	417.
	School tasks		.76						
	a. 12 easier	.185		RL	RL	3.78			
	b. 12 more difficult	−.215		RL	RL		33.7		

TABLE XIII — Specular Visual Tasks Requiring Field Factor 10. Values of Luminance (Footlamberts) for 99 Per Cent Accuracy.

Task No.	Task Description	Log $\widetilde{C}$	Visual Capacity (APS) 30	20	15	10	5	1
44.	Reading: proofed type	−.442	RL	RL	*>3160.*	1260.	302.	12.6
45.	Reading: unproofed type	−.283	RL	RL	*245.*	57.5		
46.	Reading: vernier calipers, non-etched	−.300	IL	IL	*331.*	79.5		
47.	Reading: new micrometer, etched	−.022	IL	IL	*12.9*			
48.	Reading: old micrometer	−.233	IL	IL	*120*	28.8		
	a. specular on numbers	.030	IL	IL	*8.32*			
	b. specular on division							

and luminance values for the specular tasks obtained in this way are presented in Tables XII, XIII, and XIV. In each case, the log equivalent contrast, $\bar{C}$, is given. The task reflectance is given for the non-specular tasks. The illumination or luminance value corresponding to the level of visual capacity considered to be required by each task is italicized. Reduction of the required level of visual capacity to less than 30 APS by response limitation and information limitation is indicated

TABLE XIV — Non-Specular Visual Tasks Requiring Field Factor 15. Values of Illumination (Footcandles) for 99 Per Cent Accuracy.

Task No.	Task Description	Log $\bar{C}$	R	Visual Capacity (APS) 30	20	15	10	5	1
16.	Inspection: dot defects on dark blue cloth	.562	.017	IL	IL	IL	IL	*17.8*	
17.	Inspection: gray line defect on black cloth	.369	.024	IL	IL	IL	IL	*27.5*	
18.	Inspection: darned blemish on gray cloth	−.022	.10	IL	IL	IL	IL	*74.1*	18.4
19.	Inspection: brown stitching on brown silk		.12						
	a. vertical stitching	−.398		IL	IL	IL	*>10000.*	>10000.	692.
	b. horizontal stitching	−.022		IL	IL	IL	*193.*	61.7	15.3
20.	Inspection: gray stitching on gray silk		.076						
	a. vertical stitching	−.268		IL	IL	IL	*>10000.*	4160.	155
	b. horizontal stitching	−.468		IL	IL	IL	*>10000.*	>10000.	>10000
23.	Inspection: light stitching on blue serge cloth		.018						
	a. vertical stitching	.915		IL	IL	IL	*8.45*		
	b. horizontal stitching	1.191		IL	IL	IL	*3.66*		
24.	Inspection: pattern threads, men's silk and wool suiting	−.021	.22	IL	IL	IL	*102.*	32.9	
25.	Inspection: dark brown raised threads on silk	−.180	.035	IL	IL	IL	IL	*1689.*	143.
26.	Inspection: blue-gray raised threads on silk	−.283	.046	IL	IL	IL	IL	*9650.*	281
27.	Inspection: pattern threads, white handkerchief	−.045	.91	IL	IL	IL	*31.9*		
28.	Inspection: pocket stitching, tan shirt	−.318	.53	IL	IL	IL	*>5960.*	1890.	39.4
31.	Inspection: broken white wool thread on spinner bobbin		.66						
	a. 30° illumination	.302		IL	IL	IL	IL	*1.26*	
	b. normal illumination	.042		IL	IL	IL	IL	*6.32*	
32.	Inspection: broken black thread on spinner bobbin, 30° illumination	−.174	.018	IL	IL	IL	IL	*2920.*	264.
33.	Inspection: broken gray thread on spinner bobbin, 30° illumination	.295	.079	IL	IL	IL	IL	*11.8*	
34.	Inspection: broken white nylon thread on spinner bobbin, 30° illumination	−.279	.78	IL	IL	IL	IL	*487.*	16.6
35.	Inspection: skip defect, viewed from 16 feet	−.080	.19	IL	IL	IL	IL	*71.0*	13.2
36.	Inspection: tight sound edge knot, viewed from 16 feet	.121	.19	IL	IL	IL	IL	*12.9*	
37.	Inspection: bark wave, viewed from 16 feet	−.193	.19	IL	IL	IL	IL	*381.*	28.9
38.	Inspection: small decay spot, viewed from 16 feet	−.443	.19	IL	IL	IL	IL	*>10000.*	2900.
39.	Inspection: chip grain, viewed from 16 feet	−.323	.19	IL	IL	IL	IL	*6470.*	123.
40.	Inspection: small seasoning check, viewed from 30 inches	−.181	.19	IL	IL	IL	IL	*317.*	26.4
41.	Inspection: small skip defect, viewed from 30 inches	−.148	.19	IL	IL	IL	IL	*187.*	20.7
42.	Inspection: chip grain, viewed from 30 inches		.19						
	a. no specular	−.243		IL	IL	IL	IL	*1930.*	48.8
	b. specular	.114		IL	IL	IL	IL	*13.4*	
43.	Inspection: brown color difference in cloth	−.211	.12	IL	IL	IL	IL	*870.*	56.2
50.	Inspection: brown thread stitching on brown silk tweed	−.593	.12	IL	IL	IL	IL	*>10000.*	>10000.
52.	Inspection: rolled-edge defect on white handkerchief	−.725	.91	IL	IL	IL	IL	*>3470.*	>3470.
53.	Inspection: seasoning check, viewed at 16 feet	−.545	.19	IL	IL	IL	IL	*>10000.*	>10000.
54.	Inspection: brown stain on gray cloth	−.523	.12	IL	IL	IL	IL	*>10000.*	>10000.
55.	Inspection: brown spot on red necktie	−.545	.084	IL	IL	IL	IL	*>10000.*	>10000.
56.	Inspection: brown spot on tan necktie	−.694	.18	IL	IL	IL	IL	*>10000.*	>10000.

TABLE XV — Comparative Values of Illumination or Luminance for 99 Per Cent Accuracy.

Task No.	Task Description	Method Involving: Selected FF and APS E (fc)	B (fL)	Recommended Method: FF 15 5 APS E (fc)	B (fL)
1.	Reading while writing: sample of ink-writing, one 6th grade student	2.40		1.38	
2.	Reading while writing: samples of No. 2 pencil writing, twelve 6th grade students with poorest writing in class of 31	69.0		63.0	
3.	Reading: 8-point Bodoni type	13.7		1.87	
4.	Reading: 6-point textype	27.8		2.98	
5.	Reading: 8-point textype	6.70		1.13	
6.	Reading: 10-point textype	5.38		0.94	
7.	Reading: 12-point textype	3.12		0.60	
8.	Reading while transcribing: sample of shorthand copy with No. 3 pencil	76.4		76.5	
9.	Reading: typed original, good ribbon	5.22		0.97	
10.	Reading: typed original, extremely poor ribbon	>5100.		3140.	
11.	Reading: typed carbon, fifth copy	3600.		133.	
12.	Reading: dark blue mimeograph stencil, with clear plastic overlay	18.0		3.54	
13.	Reading: Thermofax copy, poor quality	>5020.		589.	
14.	Reading: No. 2 pencil on tracing paper over blueprint	81.2		6.58	
15.	Cutting: white chalk mark on blue serge cloth	17.7		10.4	
16.	Inspection: dot defects on dark blue cloth	17.8		17.8	
17.	Inspection: gray line defect on black cloth	27.5		27.5	
18.	Inspection: darned blemish on gray cloth	74.1		74.1	
19.	Inspection: brown stitching on brown silk				
	a. vertical stitching	>10000.		>10000.	
	b. horizontal stitching	193.		61.7	
20.	Inspection: gray stitching on gray silk				
	a. vertical stitching	>10000.		4160.	
	b. horizontal stitching	>10000.		>10000.	
21.	Cutting: orange chalk on light brown tweed	292.		266.	
22.	Cutting: white chalk on gray cloth	38.2		21.0	
23.	Inspection: light stitching on blue serge cloth				
	a. vertical stitching	8.45		5.05	
	b. horizontal stitching	3.66		2.22	
24.	Inspection: pattern threads, men's silk and wool suiting	102.		32.9	
25.	Inspection: dark brown raised threads on silk	1680.		1680.	
26.	Inspection: blue-gray raised threads on silk	9650.		9650.	
27.	Inspection: pattern threads, white handkerchief	31.9		9.86	
28.	Inspection: pocket stitching, tan shirt	5960.		1890.	
29.	Reading: price tag, pencil	205.		241.	
30.	Reading: price tag, ink	5.36		3.10	
31.	Inspection: broken white wool thread on spinner bobbin				
	a. 30° illumination	1.26		1.26	
	b. normal illumination	6.32		6.32	
32.	Inspection: broken black thread on spinner bobbin, 30° illumination	2920.		2920.	
33.	Inspection: broken gray thread on spinner bobbin, 30° illumination	11.8		11.8	
34.	Inspection: broken white nylon thread on spinner bobbin, 30° illumination	487.		487.	
35.	Inspection: skip defect, viewed from 16 feet	71.0		71.0	
36.	Inspection: tight sound edge knot, viewed from 16 feet	12.9		12.9	
37.	Inspection: bark wave, viewed from 16 feet	381.		381.	
38.	Inspection: small decay spot, viewed from 16 feet	>10000.		>10000.	
39.	Inspection: chip grain, viewed from 16 feet	6470.		6470.	
40.	Inspection: small seasoning check, viewed from 30 inches	317.		317.	
41.	Inspection: small skip defect, viewed from 30 inches	187.		187.	
42.	Inspection: chip grain, viewed from 30 inches				
	a. no specular	1030.		1030.	
	b. specular	13.4		13.4	
43.	Inspection: brown color difference in cloth	870.		870.	
44.	Reading: proofed type		>3160.		>3160.
45.	Reading: unproofed type		245.		447.
46.	Reading: vernier calipers, non-etched		331.		631.
47.	Reading: new micrometer, etched		12.9		7.41
48.	Reading: old micrometer				
	a. specular on numbers		120.		148.
	b. specular on division		8.32		4.62
49.	Reading: white line on blueprint, tracing paper overlay	>5360.		>5090.	
50.	Inspection: brown thread stitching on brown silk tweed	>10000.		>10000.	
51.	Cutting: white chalk on tan cloth	>10000.		>10000.	
52.	Inspection: rolled-edge defect on white handkerchief	>3470.		>3470.	
53.	Inspection: seasoning check, viewed at 16 feet	>10000.		>10000.	
54.	Inspection: brown stain on gray cloth	>10000.		>10000	
55.	Inspection: brown spot on red necktie	>10000.		>10000	
56.	Inspection: brown spot on tan necktie	>10000.		>10000.	
	School tasks				
	a. 12 easier	3.78		2.14	
	b. 12 more difficult	123.		141	

factor, if the system is to have reasonable precision. The light factor obtained by linear interpolation is

by the abbreviations RL and IL, respectively. Table XII contains values for the non-specular tasks for which FF 10 was considered appropriate, whereas Table XIII contains data for the specular tasks for this value of the field factor. Table XIV contains data for non-specular tasks for which FF 15 was considered appropriate. Illumination and luminance values have also been determined for levels of visual capacity less than the level considered to be required by the task. These determinations were made for progressively smaller levels of visual capacity down to 1 APS, until all illumination levels for the non-specular tasks were less than 50 footcandles, and all luminance levels for the specular tasks were less than 100 footlamberts. These data make it possible to assess the level of visual capacity provided various tasks by levels of lighting less than those specified on the basis of levels of visual capacity and field factors considered appropriate to each task.

It may be of interest to compare the lighting levels established for each task from these estimates of appropriate levels of visual capacity and field factors with the levels based upon the lighting specification system recommended for current use. The values are presented for comparison in Table XV. In most cases, the differences are not large. The method based upon selected levels of visual capacity and selected field factors specifies illumination levels for ordinary reading tasks which are more in line with past recommendations. On the other hand, tasks 10, 11, and 13 seem to give extremely high footcandle values with the method of selected levels of visual capacity and field factors. It is not worthwhile speculating on the significance of these differences until further studies have been made of the processes of assimilating multiple items of information in each fixational pause, and of the field factors required for various visual tasks.

In order to evaluate the feasibility of a lighting specification system which requires selection of a level of visual capacity and a field factor for each task, we need information on the extent to which lighting levels depend upon the precise values selected. It may be noted from the curves in Figs. 28-32 that the variation in field factor from 5 to 20 has approximately the same effect upon the standard disc data as a variation in APS from 1 to 30. It should also be apparent from the curves in the figures that the effect of variations in FF or APS is greater, the lower the value of the equivalent contrast of the task.

A more quantitative assessment of the effect of the selection of FF and APS levels may be made by reference to Table XVI. Values of the luminance required for performing a given task were

TABLE XVI — Light Factors for Various FF and APS Values.

A. Log $\widetilde{C} = -.300$; Values relative to 549. footlamberts

FF	APS 30	20	15	10	5	1
5	.151	.0419	.0190	.00741	.00315	.00132
7.5	1.90	.295	.105	.0318	.0102	.00282
10	>5.75	2.46	.575	.129	.0450	.00589
15	>5.75	>5.75	>5.75	5.75	1.00	.0345
20	>5.75	>5.75	>5.75	>5.75	>5.75	.525

B. Log $\widetilde{C} = -.150$; Values relative to 32.7 footlamberts

FF	APS 30	20	15	10	5	1
5	.542	.211	.107	.0494	.0244	.0121
7.5	3.24	.929	.412	.156	.0597	.0244
10	22.3	3.36	1.27	.421	.145	.0437
15	>96.9	>96.9	16.9	3.70	1.00	.124
20	>96.9	>96.9	>96.9	40.4	10.7	.422

C. Log $\widetilde{C} = 0$; Values relative to 5.76 footlamberts

FF	APS 30	20	15	10	5	1
5	.975	.473	.262	.138	.0735	.0389
7.5	3.80	1.45	.722	.328	.155	.0758
10	14.5	3.98	1.79	.720	.300	.126
15	208.	27.3	9.55	3.02	1.00	.274
20	>550.	230.	53.6	12.3	4.35	.563

D. Log $\widetilde{C} = +.200$; Values relative to 1.47 footlamberts

FF	APS 30	20	15	10	5	1
5	1.26	.673	.435	.244	.136	.0795
7.5	3.16	1.65	.934	.495	.255	.139
10	7.76	3.36	1.76	.851	.436	.219
15	44.8	13.3	5.92	2.45	1.00	.454
20	223.	41.3	17.0	6.09	2.21	.762

E. Log $\widetilde{C} = +.400$; Values relative to .562 footlamberts

FF	APS 30	20	15	10	5	1
5	1.45	.773	.540	.310	.184	.116
7.5	2.91	1.61	1.05	.591	.322	.191
10	5.56	2.85	1.71	.938	.515	.288
15	17.1	7.66	4.12	2.03	1.00	.535
20	47.8	17.6	8.52	3.78	1.82	.855

computed for each of the FF and APS values represented by the curves in Figs. 28-32, for each of five values of log equivalent contrast of the task. "Light factors" were computed, representing the ratios of the luminances required for given values of FF and APS to the luminance required for the FF 15; 5-APS condition recommended as the current standard. These factors illustrate, most simply, the effect of the choice of FF and APS level upon the illumination level required for non-specular tasks and the luminance level required for specular tasks.

It is apparent from Table XVI that varying FF from 5 to 20 or varying APS level from 1 to 30 can vary the light factor by as much as 1000. The range of values of log $\widetilde{C}$ contained in Table XVI includes approximately two-thirds of the values obtained in VTE assessment of the 56 practical tasks, so that the light factors presented in the table give a reasonable estimate of the effect of FF and APS levels for all the tasks studied. This analysis suggests that it is going to be necessary to develop fairly precise procedures for selecting values of the visual capacity level and the field

factor, if the system is to have reasonable precision.

Of course, the light factors presented in Table XVI may be used to estimate the lighting levels which would have been recommended for the 56 tasks, had different levels of capacity and/or a different field factor been selected.

For example, consider task 9, for which $\log \tilde{C} = +.397$. The illumination level specified by the FF 15, 5 APS-system is 0.97 footcandles. Suppose the illumination level were desired corresponding to the FF 10, 30 APS condition. The value of $\log \tilde{C} = +.400$ in Table XVI is the most similar to the $\log \tilde{C}$ value of the task. The light factor for FF 10 and 30 APS is 5.56. The estimated illumination level is $0.97 \times 5.56 = 5.38$ footcandles. The illumination level actually computed for the FF 10, 30 APS-condition is presented in Table XII as 5.22 footcandles. Similarly, task 45 has a value of $\log \tilde{C} = -.283$. We may estimate the luminance for this specular task for the FF 10, 15 APS-condition from the value for the FF 15, 5 APS-condition given in Table VI as 447. footlamberts. The light factor for $\log \tilde{C} = -.300$ is nearest the $\log \tilde{C}$ value for the task; it is given in Table XVI as .575. The luminance is, therefore, $447. \times .575 = 257.$ footlamberts. The value obtained by precise calculations, and presented in Table XIII, is 245. footlamberts. Use of the light factors presented in Table XVI results in a close approximation in these cases, since the value of $\log \tilde{C}$ for the task in each case so nearly approximated a value contained in the table. Since there are five values of $\log \tilde{C}$ presented in Table XVI, it will usually be possible to come reasonably close by applying the light factor corresponding to the most nearly equivalent value of $\log \tilde{C}$.

Of course, it will be possible to come even closer by use of linear interpolation between the light factor values contained in Table XVI. The following are illustrations of this technique. Consider task 48a, for which the value of $\log \tilde{C}$ is $-.233$. The luminance for this specular task for the FF 15, 5 APS-condition is given in Table VI as 148. footlamberts. The light factors for conversion to the FF 10, 15 APS-level are 1.27 for $\log \tilde{C} = -.150$ and .575 for $\log \tilde{C} = -.300$. The light factor value obtained by linear interpolation is .885. Luminance is therefore estimated as $148. \times .885 = 131.$ footlamberts. The value obtained by precise calculations is presented in Table XIII as 120. footlamberts. Similarly, for task 30, the value of $\log \tilde{C} = +.127$. The illumination for this non-specular task for the FF 15, 5 APS-condition is given in Table VI as 3.10 footcandles. The light factors for conversion to the FF 10, 15 APS-level are 1.79 for $\log \tilde{C} = 0$ and 1.76 for $\log \tilde{C} = +.200$. The light factor obtained by linear interpolation is 1.77. The illumination is therefore estimated as $3.10 \times 1.77 = 5.48$ footcandles. The value obtained by precise calculations is presented in Table XII as 5.36 footcandles. These examples illustrate that use of interpolation between the light factors presented in Table XVI leads to satisfactory estimates of illumination and luminance levels for different values of FF and APS than those for which calculations have been reported.

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Current Status of Some Other IERI Projects

Illuminating Engineering Research Institute

1860 Broadway, New York 23, N. Y.

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RESEARCHES on the amount of light required for visual tasks are recorded in this issue (see page 317). Even as to quantity of illumination, however, the questions have not as yet all been answered. Dr. Blackwell's tests were conducted with twenty-year-old subjects — what of older or younger eyes? Or eyes with subnormal vision? How much light does the eye need for focusing, with a minimum of fatigue? What is the limit of tolerance? What of discomfort glare?

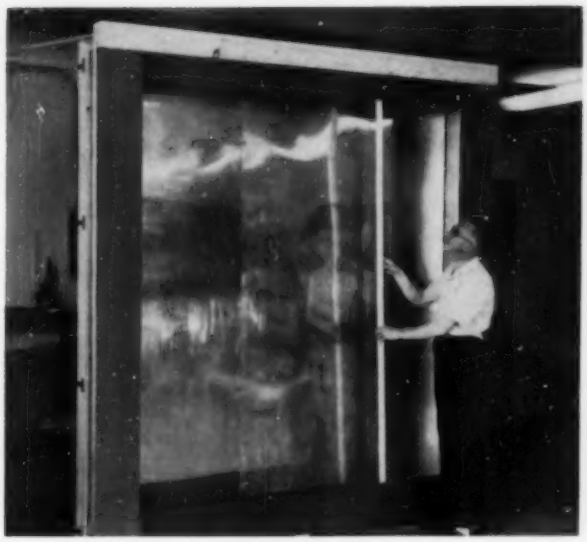
These and other problems in the relationship between lighting and vision are the subjects of continuing study sponsored by the Illuminating Engineering Research Institute. Scientific progress reported at the Dearborn Symposium includes the unveiling of a new portable meter for measuring disability glare, developed by Dr. Glenn A. Fry, Professor of Physiological Optics at Ohio State University; and a similar meter for measuring discomfort glare, the work of Dr. S. K. Guth, Manager, Radiant Energy Effects Laboratory of General Electric in Cleveland (see page 398).

Still other research projects currently being sponsored, and some nearing completion, include studies in the fields of glare from large light sources, roadway lighting requirements, an extension of fog studies, reflections from glossy materials and color preferences.

Glare From Very Large Sources

An interesting feature of this research is that it is being conducted simultaneously in England and the United States. It is an outgrowth of earlier studies by Dr. Ralph G. Hopkinson, Principal Scientific Officer, Building Research Station in Garston, England. With the increasing use of picture windows in homes, glass-sided office buildings and large luminous panel lighting systems, Dr. Hopkinson extended his researches, two years ago, under IERI auspices. His American colleague is Robert C. Bradley, Research Associate, Cornell School of Electrical Engineering in Ithaca, N. Y. Similar experiments are being conducted in both laboratories.

Dr. Ralph G. Hopkinson, Principal Scientific Officer, Building Research Station, Garston, England, with his original study equipment at his British laboratory, left.



At right, he assembles the larger, 7-foot-square, equipment for the Cornell University counterpart of his glare study, where work is being conducted by R. D. Bradley.

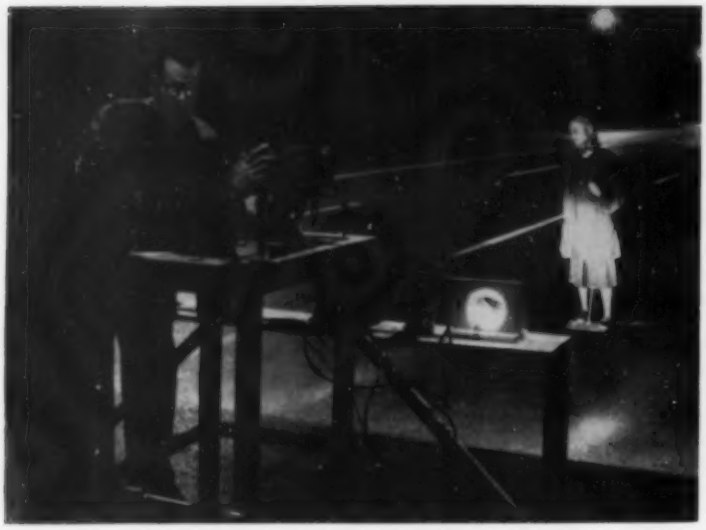
The experimental arrangement is based on a very large uniform source consisting of a bank of closely-packed fluorescent lamps whose light is diffused by an opal screen, so presenting a large surface of uniform brightness to the observer. A system of dimmers permits control of the luminance of this source. A series of masks placed over the source and the distance of the observer from the screen provide a range of source sizes. Surround luminance is supplied by other fluorescent lamps, also on dimmers, set in a system of screens such that a substantially uniform surround luminance is seen by the observer with as little interference with the source luminance as possible. Results thus far indicate that brightness from the screen is less unfortable if the surround is also lighted.

Another IERI project recently completed by the Hopkinson-Bradley team covers Estimation of Discomfort Glare Magnitude. This study, a by-product of the work on glare from large sources, is scheduled for publication in the August 1959 issue of ILLUMINATING ENGINEERING. The report includes very promising results of numerically evaluated estimations on glare sensation made by "naive" observers. (Experience has shown that non-scientific people can make these judgments more readily than those trained in the mathematical sciences.)

Visual Task Evaluator at beginning of a roadway test.

Roadway Lighting Requirements

This project, at the Institute for Research in Vision at Ohio State University, is a direct outcome of the development of the Blackwell Visual Task Evaluator. At the request of the IES Roadway Committee, this instrument has been adapted to measure perceptibility of objects at various distances under existing lighting conditions on an average roadway. How much light *is* necessary to see obstacles in time to stop a vehicle safely from a speed of 30 miles per hour, 40, or perhaps 50 miles



Dark-coated model — size of an average 11-year-old girl — and her black Scotty dog, placed close to the testing device for a trial run in the studies of perceptibility under existing roadway lighting in Columbus, Ohio.

per hour? A life-sized three-dimensional figure of an 11-year-old girl and her black Scotty dog are the subjects for observation in these tests, by observers 25 feet away with instruments placed in the relative position of an oncoming car.

Visibility in Fog

Fog — a major problem on many high-speed turnpikes — is being tackled by a two-phase program at Pennsylvania State University, University Park, Pa., and at Ohio State University in Columbus. Dr. Blackwell, in previous studies sponsored by IERI at the University of Michigan, had established curves showing that the degree of scatter effect is greater when fog is illuminated by beams of light parallel to the observer's line of sight and that it is less as the beams approach a line perpendicular to the observer's line of sight.

In putting these data to a practical test, Prof. Charles Marsh, at Pennsylvania, simulated a turnpike roadway in a 50-foot army tent. He had earlier developed a simulated fog, with all the qualities of nature's own product, and this was introduced in controlled amounts into the tent, through pressure jets at the side of the installation. Through tests with assorted types of lighting installations, it was shown that visibility through fog can be increased up to 100 per cent by lowering car lights to bumper level, by introducing

Scale model "fog-box," about 35 feet long.

Before fog enters test box from jets.

Fog equal to 60-foot visibility. Overhead lighting approximates a turnpike installation.

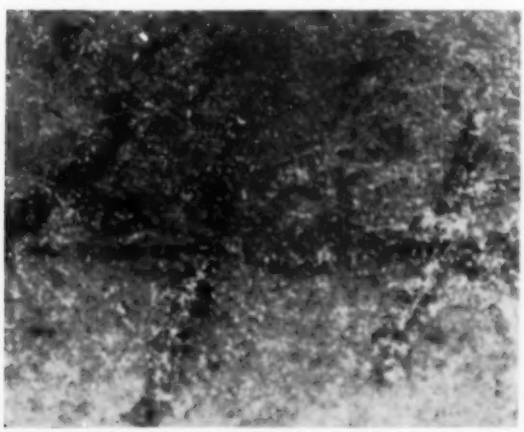
Fog equal to 60-foot visibility. Lighting is improved with use of downlights.

lighting from the side of the road slightly above the surface of the turnpike and by narrowing the beam of overhead lights and directing them downward. Each of these techniques brings the light beam closer to a line perpendicular to the observer's line of sight.

Conducting his experiments with the same line of thinking, Dr. Blackwell and his aides at Ohio State have constructed a scale-model "fog-box" about 35 feet in length. Results obtained with this 8:1 scale model can be seen from the photographs of the tests shown above.

Reflections from Glossy Materials

Even so-called non-glossy surfaces can produce a surprising loss of contrast and, therefore, of visibility. Two projects now being completed have investigated methods of measurement of the degree of loss of contrast under given lighting systems. At the University of California, Prof. Dan M. Finch has arrived at his results by sweeping a pencil of light through a series of planes and measuring the reflectance from background and detail at a series of angles. In this way, the degree of loss



Photograph of a boy's handwriting on matte paper with glossy reflections of the overhead lighting. 65-degree incident light; 25-degree viewing angle (25 degrees to normal).

The same sample of handwriting with the light directed to minimize glossy reflections from the paper background. 90-degree incident light; 25-degree viewing angle (0 degrees to normal).

of contrast in any given lighting system can be calculated.

In Toronto, Ont., John M. Chorlton and Hedley F. Davidson, affiliated with the Board of Education and Curtis Lighting of Canada, Ltd., respectively, have been reaching similar conclusions by directly — visually — measuring loss of contrast. Conducting their studies in a typical public school classroom, they made their physical measurements at the student's normal eye position.

By applying the Blackwell report data to the measured losses of contrast, compensation can be made by increasing the level of illumination by a calculated amount. Or, losses can be reduced by diminishing the downward component of the lighting source.

Color Preferences

What effect do stimulus-background combinations have on color preferences? What relation is there between spectral energy distributions of sources and pleasantness of colors? What generalizations can be made regarding the relation of dominant wavelength and purity of sources of illumination to color preferences? These questions are being studied in a project at the University of Texas under the direction of Dr. Harry Helson. Observations are being made by a large group of subjects, both men and women, on standard Munsell colors in a wide range of hues, lightness and saturation. Observations are made in light-tight booths illuminated by each of several different sources. Observers report on the pleasantness of the samples and of the sample-background combinations. By modern statistical methods it is possible to analyze the trends in color preferences as related to the various background colors. No report has as yet been made on the findings of this recently initiated study.

Transitional Adaptation

Another project recently begun, for which it is still too early to report results, is that going on at the University of Rochester under the direction of Dr. R. M. Boynton, Professor of Psychology. The problem being investigated is the change in the ability of the eye to see objects immediately when moving from a dark area to a light area or vice versa, such as looking out the window and back to the work, or entering or leaving a tunnel.

For the Future

Five other new projects have been contracted for. These are:

(1) Visual studies using the field task simulator,

(2) Measurement of school tasks and study of oculomotor functions (focusing),

(3) Development of a prototype Visual Task Evaluator for field use,

(4) Extension of the earlier work with the field task simulator and the Visual Task Evaluator to include dynamic use of the eyes,

(5) Development of instruments for studying illumination requirements of persons who are visually handicapped.

Register Early for National Technical Conference

Registration blanks for the National Technical Conference of IES, to be held in San Francisco, Calif., September 7-11, are being mailed to all members of the Society now. Register early for this top IES meeting. Forms should be sent to the New York headquarters office.

Recommeded Levels in Current Practice

- Industry
- Offices
- Schools

Although a survey of industry opinion (see page 374) indicates only a small percentage of current installations meet current recommended levels, there are, nevertheless, a goodly number which do. Since virtually all these installations preceded the publication of the new IES footcandle recommendations, it would appear that, to some extent at any rate, actual practice has been in advance of science. Since it would also appear that these pace-setting lighting installations occur most frequently in industrial areas and offices — where any gain which may be attributed to lighting can most easily be appraised — it might be concluded that field experience has long corroborated what research indicates is needed for fast and accurate seeing.

It goes without saying, of course, that the key to the success of any installation meeting current levels has been the application of *all* the principles of good lighting. Shielding — direction — reflectances — control — brightness ratios — in a word, *illuminating engineering* — are more important than ever. And they've always been a consideration for anything greater than moonlight. To these might also be added: appropriate design for the area lighted — consideration of the materials used (brick, marble, whatever) — esthetic appreciation of the architect's design — an eye to pleasantness. Again, in a word, *illuminating engineering.*

A garnering, countrywide, of pictures of current practice with current levels, turned up some examples in almost every phase of lighting practice. Three of these areas are featured on the following pages. More — stores, banks, public buildings, outdoor areas and others — will appear in the July and August issues.

Rough assembly work in the manufacture of large valves is done in this 13,000 square foot area. Porcelain enamel industrial fixtures with 25 per cent upward component are mounted on 15- by 20-foot centers and use 8-foot extra-high-output lamps. Walls are light green, ceiling is white, floor is cement. Illumination level is 60 footcandles. (A)

• INDUSTRY

Benefits accruing from lighting installations which meet IES recommendations in industry are probably more evident, and documented, than in many other areas. Records show that increased production, fewer rejects, faster inspection and reduced number of accidents often offset the cost of the installation in a very short time — to say nothing of improved worker morale.

Since, in most industrial areas, the task does not vary considerably over the work day or week, these records are valuable confirmations of the importance of both the quantity and quality illumination recommendations.

It should be noted again that, as in all other types of areas, the recommended levels of illumination are *minimum on the task at all times.* Maintenance programs should probably be on a more frequent schedule for industrial installations than in most others.

Many industrial operations have been found to require illumination levels far above those practicable, or necessary, for general lighting. In these cases supplementary lighting may be required to meet the stipulated conditions.

(Photo credits for this section are on page 363, keyed to the letter at the end of each caption.)

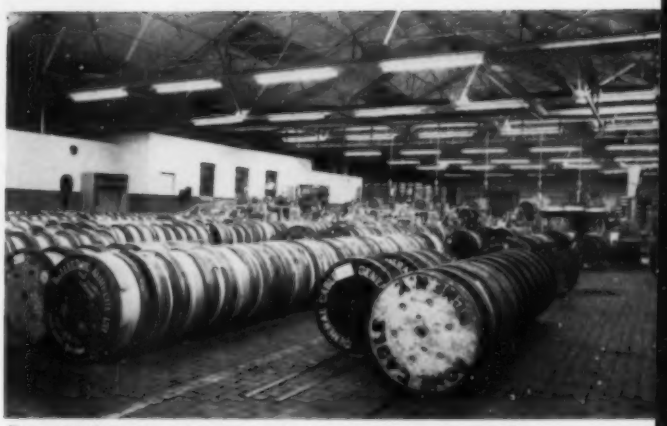
A combination of two four-lamp fluorescent systems provides 500 footcandles on the work plane in an air craft assembly area. Fixtures suspended 5 feet over the benches have egg-crate louvers and use 8-foot high output lamps. Other units, mounted on the ceiling, are equipped with 8-foot slimline lamps. (B)

Recommendations for Some Typical Tasks in Industry

	Currently Recommended Illumination* Footcandles
ASSEMBLY	
Rough easy seeing	30
Rough difficult seeing	50
Medium	100
Fine	500
Extra fine	1000
INSPECTION	
Ordinary	50
Difficult	100
Highly difficult	200**
Very difficult	500**
Most difficult	1000**
MACHINE SHOPS	
Rough bench and machine work	50
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	100
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing	500**
Extra fine bench and machine work, grinding, fine work	1000**
MATERIALS HANDLING	
Wrapping, packing, labeling	50
Picking stock, classifying	30
Loading, trucking	20
Inside truck bodies and freight cars	10
STORAGE ROOMS OR WAREHOUSES	
Inactive	5
Active	
Rough bulky	10
Medium	20
Fine	50
STRUCTURAL STEEL FABRICATION	50

*Minimum on the task at any time.

**Obtained with a combination of general lighting plus specialized supplementary lighting. Care should be taken to keep within the recommended brightness ratios. These seeing tasks generally involve the discrimination of fine detail for long periods of time and under conditions of poor contrast. To provide the required illumination, a combination of the general lighting indicated plus specialized supplementary lighting is necessary. The design and installation of the combination system must not only provide a sufficient amount of light, but also the proper direction of light, diffusion and eye protection. As far as possible it should eliminate direct and reflected glare as well as objectionable shadows.

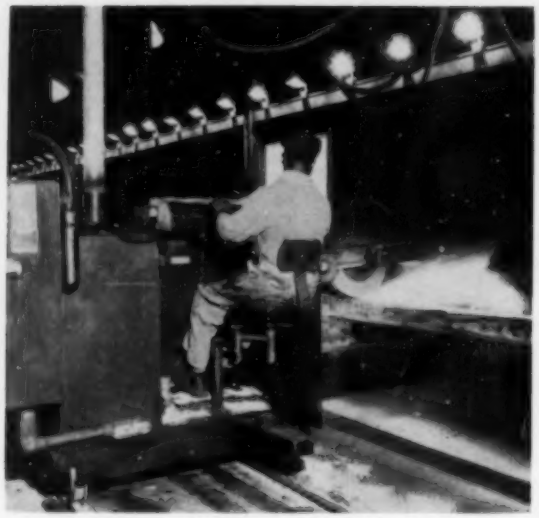


Extra-high-output lamps in industrial fixtures supply 60 footcandles after 1600 hours, in a cable warehouse. (C)

Four-lamp louvered luminaires with 35-degree cut-off using 8-foot slimline lamps provide 155 footcandles in a machine shop. (D)

General lighting level in maintenance area is 70 footcandles from two-lamp aluminum units with upward component, using extra-high-output lamps. Here fixture spacing is 12 by 12 feet at mounting height of 19 feet. In the meter area in the rear, 100 footcandles are supplied by continuous rows of the same fixtures. Benches and floor have light surfaces. (E)

Mounting height is 30 feet in the storage bin area on the left, and 40 feet in the heavy storage area at right. Two-lamp 8-foot units with upward component are spaced on 15- by 25-foot centers. Average maintained level is about 25 footcandles. (F)



Levels of 500 footcandles maximum and 300 footcandles average allow this machine operator to inspect the work while sitting on his machine, in a grinding operation to remove scale and surface defects from steel blooms and ingots. A total of 81 300-watt PAR56 medium flood lamps are mounted on 27-inch centers, 9 feet above the floor and 6 feet from the work. (G)

Mercury and fluorescent sources here combine in a high-bay area (right) of a locomotive works, to provide a maintained level of 60 footcandles. Two-lamp 8-foot extra-high-output fluorescent units alternate with two-lamp 400-watt H1LK improved-color mercury luminaires. Units are spaced on 18½- by 12½-foot centers and are mounted 47 feet above the floor. (H)

Loading operations and truck movement are carried on under 30 footcandles illumination from two-lamp 8-foot units with upward component, using extra-high-output lamps. Mounting height is 28 feet. (I)

Average illumination in this 903- by 320-foot manufacturing area is 80 footcandles. Porcelain enamel industrial fixtures with upward component are mounted in rows on 20-foot centers with 2 feet between units, at 30 to 40 feet from the floor. Lamps used are 1458 extra-high-output and 726 high-output cool white fluorescent. (J)

Rough bench and machine work is done in this plant area where 80 footcandles are supplied by two-lamp 8-foot extra-high-output lamps in industrial fixtures. (K)

A combination of 1000-watt improved-color H15GW mercury units and 8-foot T12 high-output fluorescent fixtures is used on a 480/277 distribution system in this turbine building. Average illumination is 110 footcandles. Units are mounted at 30 feet. (L)

Photo Credits — Industrial Areas

Photos A, B, E, F, G, H, I, J and L: General Electric Co., Cleveland, Ohio.

Photo C: Sylvania Lighting Products, Division of Sylvania Electric Products Inc., Salem, Mass.

Photos D and K: Texas Power and Light Co., Dallas, Texas.

Flexibility in use of office space is provided by the use of movable partitions, with overall luminous ceiling. Level is 100 footcandles. Louvered recessed troffers are used over corridor area. (M)

• OFFICES

Visual tasks in offices are frequently of the type which change in severity over short periods of time. A secretary or executive may, one moment, be reading a fourth carbon copy of a letter and then a clear ribbon copy. A draftsman may be tracing from an old blueprint and his next job will be copying from a clear photostat. This diversity in seeing task holds true also for conference rooms and similar office areas.

In such instances, IES recommended levels of illumination should conform to the need of the most difficult task to be performed in the area. These recommendations, in addition, all contain the stipulation, *minimum on the task at all times.* Where an installation meets recommended practice initially, the levels must be maintained through proper cleaning, re-lamping, re-painting.

All the quality principles for efficiency and comfort — recommended brightness ratios, matte surfaces for office equipment, shielding of luminaires — apply, of course, with the new levels. In fact, they will probably be more important than ever. The application of current lighting practice to achieve both the quantity and quality of lighting recommended in offices may require imagination and foresight in addition to engineering skills.

(Photo credits for this section are on page 367, keyed to the letter at the end of each caption.)

Illumination levels of from 75 to 85 footcandles are provided on the center table in this conference room, and 100 on a wall display table. Ceiling-mounted units with plastic diffusers are arranged in a center panel and two side rows. Maximum brightness ratio, from task on center table to side rows at 30 degrees, is less than 6:1. (N)

Dimensions are 18 by 30 feet with an 18-foot ceiling in a recently partitioned area, where levels of 130 footcandles were measured on desk tops after five months operation. Extra-high-output lamps are used in four rows of two-lamp suspended fixtures with 24- by 30-degree shielding and 25 per cent uplight. O)

Approximate lighting level of 175 footcandles is supplied in this drafting room. Egg-crate luminous ceiling is suspended below 40-watt fluorescent lamps in single and double strips, alternately, on 18-inch centers. (P)

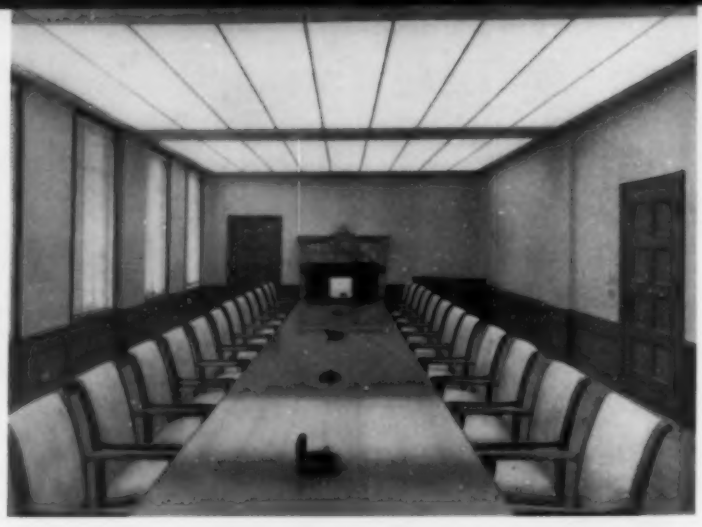
Recommendations for Offices

	Currently Recommended Illumination* Footcandles
Cartography, designing, detailed drafting	200
Accounting, auditing, tabulating, bookkeeping, business machine operation, reading poor reproductions, rough layout drafting	150
Regular office work, reading good reproductions, reading or transcribing handwriting in hard pencil or on poor paper, active filing, index references, mail sorting	100
Reading or transcribing handwriting in ink or medium pencil on good quality paper, intermittent filing	70
Reading high contrast or well-printed material, tasks and areas not involving critical or prolonged seeing such as conferring, interviewing, inactive files and washrooms	30
Corridors, elevators, escalators, stairways	20 (or not less than ⅓ level in adjacent areas)

*Minimum on the task at any time.

Secretarial area has 70 to 80 footcandles on the desks, using ceiling-mounted units. A row of similar units along the wall, in visitors' waiting area, highlights decorative plaque. (Q)

A total of 152 two-lamp louvered troffers provide an average maintained level of 135 footcandles after a year and a half of operation in this 2540-square-foot general office. Light surfaces are used throughout. (R)



Two levels of illumination — 80 and 160 footcandles maintained — are provided in this Board of Directors room. Recessed units have 2- by 2-foot double vinyl plastic diffusers. (S)

Private office is lighted to levels of 440 to 520 footcandles on the desk with 200 on the telephone table. Light-colored surfaces insure good brightness ratios. (T)

General office area of approximately 1100 square feet has average lighting level of 155 footcandles, from surface-mounted luminaires with plastic diffusers. Dark file cabinets do not meet IES recommendations. (U)

A "floating" panel of four 8- by 7-foot units gives a dropped ceiling appearance without any wall attachments. Shielding is composed of polystyrene plastic dishes. Illumination level is about 100 footcandles. (V)

Ceiling-mounted luminous panels are used as an element of decorative design, in addition to supplying 140-150 footcandles on the desk and 120 at the telephone table. (W)

A higher than usual reflection factor of 75 per cent was selected for walls of this drafting room, to reduce the brightness ratios with the corrugated plastic luminous ceiling. Average footcandles maintained on the drafting tables are 190, on desks along the wall, 150. (X)

Photo Credits — Office Areas

Photo M: General Electric Co., Cleveland, Ohio.
Photo N: Day-Brite Lighting, Inc., St. Louis, Mo.
Photo O: J. A. Frederickson, General Electric Co., Seattle, Wash.; second place winner in the Puget Sound Section's contest for My Most Interesting Lighting Job.
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Photo S: Pacific Gas and Electric Co., Portland, Ore.
Photo T: Day-Brite Lighting, Inc., St. Louis, Mo.
Photo U: Ohio Edison Co., Akron, Ohio.
Photo V: Smitheraft Lighting Co., Chelsea, Mass.
Photo W: Day-Brite Lighting, Inc., St. Louis, Mo.
Photo X: San Diego Gas and Electric Co., San Diego, Calif.
Photo Y: Columbia Electric and Manufacturing Co., Spokane, Wash.
Photo Z: Silvray Lighting, Inc., Bound Brook, N. J.
Photo AA: San Diego Gas and Electric Co., San Diego, Calif.

Recessed four-lamp units with low-brightness white crystal glass diffusers provide up to 170 footcandles in an engineering drafting room. Vertical louvers give protection in long window wall. Surfaces are light. (Y)

Four rows of suspended units, 12½ inches from ceiling to bottom of fixture, are spaced on 4-foot centers and supply 135 footcandles on the desk. Walls are of light mahogany paneling; ceiling, acoustical tile; rug is beige. (Z)

Average illumination in this 7581-square-foot general accounting department is 135 footcandles. Rows of three-lamp recessed troffers, with plastic lens diffusers, are spaced on 8-foot centers. (AA)

Ceiling-mounted fixtures, with diffusing louver shielding and four 40-watt rapid-start lamps each, provide 85 footcandles in this 28- by 30-foot classroom. (BB)

(Photo credits for this section are on page 371, keyed to the letters at the end of each caption.)

Lecture room (below) is lighted to 115 footcandles maintained by a large luminous element composed of 4-foot-square louvered panels. The unit is so mounted as to give a dropped-ceiling effect. Louvers provide 45- by 45-degree shielding. (CC)

• SCHOOLS

In the usual educational set-up, as in offices, a great variety of visual tasks are performed in a single classroom. And the lighting must be planned for the most difficult. During normal classroom hours, daylight can be utilized to supplement the lighting installation, and the control of daylight through proper shielding should be considered a part of the lighting engineering.

As public institutions, however, classrooms are often used for community activities or adult education programs at night, and the electric lighting installation, alone, must provide adequate levels for the visual tasks involved.

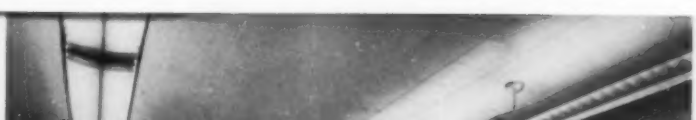
Illumination levels for schools have been excerpted from the *IES Lighting Handbook*, Third Edition.

	Currently Recommended Illumination* Footcandles
Reading printed material	30
Reading pencil writing	70
Spirit duplicated material	
Good	30
Poor	100
Drafting, benchwork	100**
Lip reading, chalkboards, sewing	150**

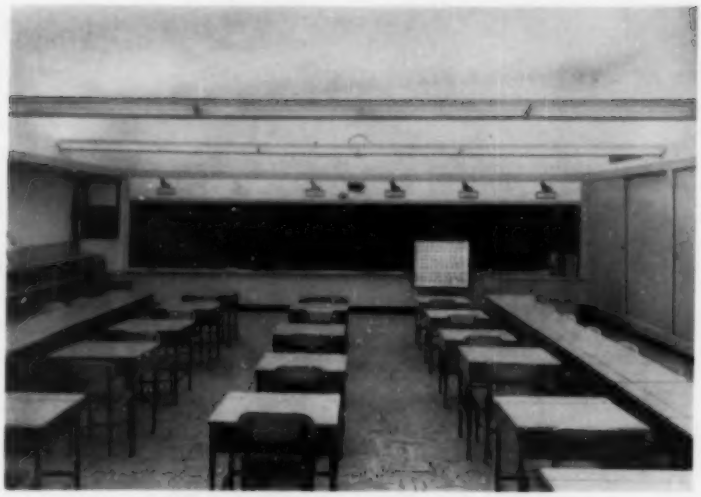
*Minimum on the task at any time.

**Obtained with a combination of general lighting plus specialized supplementary lighting. Care should be taken to keep within the recommended brightness ratios. These seeing tasks generally involve the discrimination of fine detail for long periods of time and under conditions of poor contrast. To provide the required illumination, a combination of the general lighting indicated plus specialized supplementary lighting is necessary. The design and installation of the combination system must not only provide a sufficient amount of light, but also the proper direction of light, diffusion and eye protection. As far as possible it should eliminate direct and reflected glare as well as objectionable shadows.

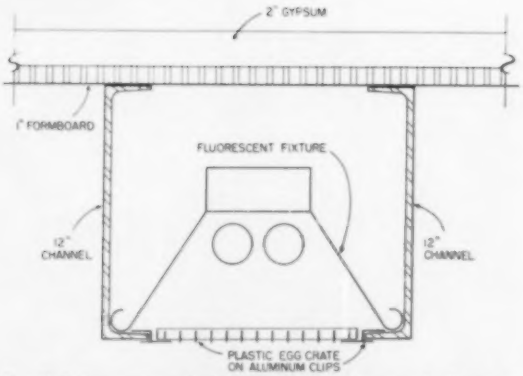
Maintained level is 70 to 75 footcandles in this classroom, from two-lamp fixtures with Alzak aluminum louvers and 96-inch high-output rapid-start lamps. Dark chalkboard and cabinet in front of the room do not meet IES recommended practice. (DD)



Three-lamp indirect fixtures, in 24-foot rows, use 54 four-foot warm white rapid-start lamps. Initial levels measured on desk tops were: maximum, 122 footcandles; minimum, 86; average, 101 footcandles. Walls, ceiling and furniture surfaces are light in color, but dark chalkboard does not meet IES recommendations. (EE)



Continuous rows of two-lamp 800-milliamp luminous indirect luminaires supply 65 to 70 footcandles maintained. This level is increased to 135 footcandles with the addition of daylight. Suitable shielding for that potential source of high brightness and direct glare is, of course, essential. (FF)



The lighting system is built into the structural elements of this school, being housed in the channel which supports the roof. Industrial-type fixtures are recessed in the channel, which is painted to blend with the formed board ceiling and classroom trim. Plastic egg-crate grids, held in place with aluminum clips, provide shielding. Five four-foot fixtures are housed in each of the three rows of boxed channel. (GG)

Arranged in a "W" pattern, suspended louvered luminaires with upward component each use two 40-watt T12 rapid-start lamps for a level of 70 footcandles. (HH)

Two-lamp indirect units, pendant-mounted in continuous rows on 12-foot centers are used in the central area library and workshop at the administration headquarters building of a school system. Ceiling height is 10½ feet and fixtures are mounted at 8½ feet. Illumination is 45 footcandles on the reading task. (II)

Luminous panels, each using eight 40-watt T12 warm white lamps, are spaced on 10- by 10-foot centers. Average illumination in this art and music room is 90 footcandles. (JJ)

Photo Credits — School Areas

Photo BB: The Edwin F. Guth Co., St. Louis, Mo.

Photo CC: Smitheraft Lighting Co., Chelsea, Mass.

Photo DD: Texas Power and Light Co., Dallas, Texas.

Photo EE: San Diego Gas and Electric Co., San Diego, Calif.

Photo FF: Smoot-Holman Co., Inglewood, Calif.

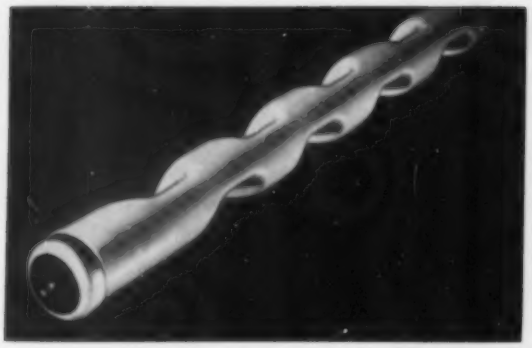
Photo GG: Jones & Laughlin Steel Corp., Pittsburgh, Pa.

Photo HH: General Electric Co., Cleveland, Ohio.

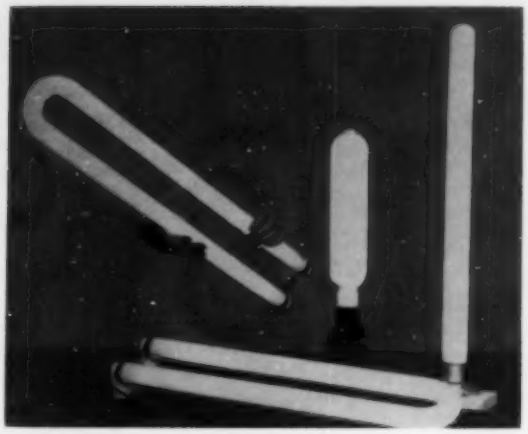
Photo II: Sunbeam Lighting Co., Los Angeles, Calif.

Photo JJ: General Electric Co., Cleveland, Ohio.

New Twists for

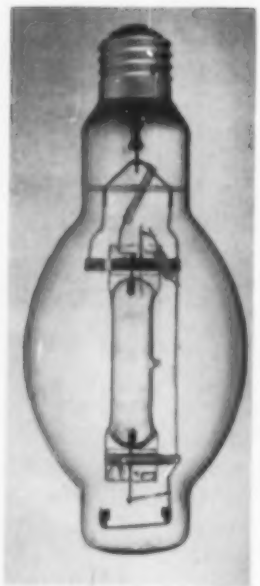


Lamps with grooving on both sides of the tube increase light output by 15 per cent over the earlier non-circular design — for the 8-foot lamp, 15,000 lumens at 70 lumens per watt. The wavy arc path, 9 feet long in an 8-foot tube, results in light output that is equivalent to that from a 9-foot straight lamp.



Fluorescent lamps with a base at one end only and U-shaped lamps which require wiring and sockets at only one side are two new developments in the laboratory stage which may have an influence over application designs. The U-shaped lamp is reported to have an efficiency equal to or greater than the straight tubular type and has only half the overall length of a standard 75-watt lamp.

Another U shaped lamp (left) is not only on the market but has been used in an application with a fixture especially designed for it. Note: a plastic egg-crate ceiling is to be installed below the lamps in this application.



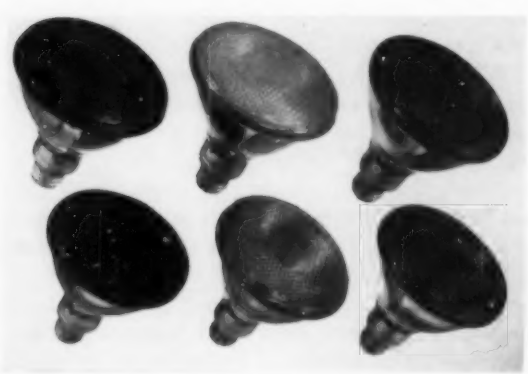
Some of the older sources, also, may be in for re-design. For the 400-watt mercury lamp (left), as an example, new double-wound cathodes with new emission coating virtually eliminate arc tube blackening, thus improving lumen maintenance — 80 to 87 per cent of initial light output is maintained after 8000 hours. As a result, the economic life rating of the lamp has been increased 50 per cent — 9000 instead of 6000 hours. Low-temperature starting is easier. At —20 F the starting voltage required is 225 volts instead of the 300 volts required by the regular 400-watt lamps. Lamps operate on smaller, lighter-weight, less expensive ballasts, the H33 type. Other new construction features include a strong, simplified mount structure and an improved resister.

Light output of the 1000-watt RB-52 lamp (right) has been increased from 16,300 to 18,000 lumens by the adoption of the CC-8 (instead of C-7A) filament construction. The combination of bulb shape, filament design and filament positioning are said to provide 20 to 30 per cent more light on the work plane.

Light Sources

PAST experience with "new" recommended levels, and current opinion also (see page 374), suggest that there may be in store some interesting changes in lighting equipments stemming from advances in lighting practice. Several recent developments in light sources, for example — and there will undoubtedly be more to come — include: an increase in lumen output of existing lamp types, new filters for improved color rendition, and a lengthening of lamp life. Other developments, some still experimental, include changes of source shape and size, socket and wiring requirements and built-in ballasts. These characteristics may influence fixture design and methods of mounting. A trend toward "area" lighting systems might be read into some of the laboratory models of large surface sources being developed.

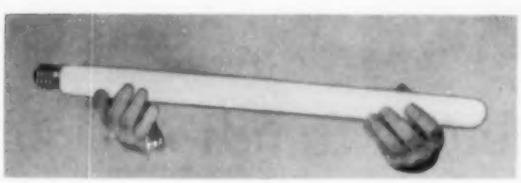
A new 40-watt fluorescent lamp, rated at 3100 lumens, has recently been announced in standard cool white color. Features contributing to the higher luminous efficacy claimed for the lamp are: a new extra-uniform phosphor of finely controlled particle size, addition of anodes to the regular cathode electrodes, and a new current-carrying gas mixture. The lamp is said to have a rated life of 7500 hours on rapid-start circuits and over 5000 hours on preheat ballasts with manual reset starters.



Baked-on silicone color-filter coating for the 100-watt PAR-38 lamp (left) transmits more light than did the filters on the 150-watt color lamps, particularly in the blue and green colors, where they actually provide more light than did their predecessors. The new lamps are said to be better balanced in colored-light output — greens and blues not being overpowered by warm colors. The lamps are weatherproof, requiring no protection from rain, sleet or snow, in any burning position.

Experimental square fluorescent lamp is made by sealing two channeled plates of glass together to form a nearly flat panel approximately one foot square and about an inch thick. Although its commercial introduction cannot as yet be predicted, laboratory reports state that it can be made available in a wide variety of brightnesses and colors.

Another square or rectangular fluorescent lamp is being developed — one laboratory model measuring 24 inches long by 8 inches wide by 1 inch thick and another 12 inches square and 1 inch thick. Some models have a reflector coating on one surface so that all light is directed through the other side. Patterned glass can be used to control the brightness and direction of light.



A fluorescent lamp requiring no external ballast or starter, which can be burned in a standard screw-type socket, is in the development stage. The lamp contains a built-in bi-metal starting switch and an incandescent filament which makes the external inductor ballast unnecessary. The incandescent filament also adds its light to the total lumen output of the lamp and serves as a color-improving factor, augmenting, with the red end of the spectrum, the blue-green end common to the more efficient fluorescent phosphors.

Highlights from a cross-section ...

- Quality, quality, *quality*. Everyone views with alarm the possibility of missing this, when applying higher levels. Lighting practitioners have a *vital responsibility* to sell the importance of quality. So says everyone, in a cross-section of their views on higher levels.
- When you break 100 (fc), things happen. Btu's go up; luminaire design becomes critical; balanced brightnesses become *vital*. 100 fc and up more than ever requires an engineered job.
- Upper range of comfortable brightness above the adaptation level decreases as the adaptation level increases. So higher footcandles should influence luminaire design with special attention to brightnesses in the field of view.
- Acceptance of 8 or 10 APS must surely come (and not 5 APS on which current levels are based). So we should be prepared with equipments and techniques for the next upward revision in recommended footcandle levels.
- There may be obstacles to higher levels — like air-conditioning needs, for example — but the advantages are too great to deter progress. They're great enough to cover *both* costs.
- Economy is a component in the merit of any lighting system.
- Just how "high" are we talking about, when we say "higher levels." Since the footcandle levels are in relation to the difficulty of the tasks, by and large for most seeing tasks, we are talking about 150 footcandles and below.
- New techniques must be worked out with the acoustical and heating-air-conditioning engineer. We can't overcome one deficiency while ignoring the other comfort factors.
- Combination of lighting-with-heating is just around the corner.
- There may be a large number of sour higher level jobs in the next year or so. A poor job at 200 fc is worse than a poor job at 50 fc.
- Wide application of higher lighting levels hinges upon availability of suitable equipment — both light sources and fixtures.
- The only areas which are reasonably prepared, equipment-wise, to furnish recommended levels economically are in industrial lighting.
- There are quite a few bugs still in extra-high-output lamps and auxiliary equipment. We should expect to see lots of new developments in lamps in the next year or so.
- About 10 per cent of commercial and industrial areas now meet recommended practice, per the opinion of most lighting men. Homes, much less.

A survey of opinion on

Future Trends in Lighting

Whether pro or con, cautious or confident, shop-talk in lighting circles swings invariably to the higher footcandle levels, and the zillion-and-one ramifications in employing them. Panels, forums and lectures will no doubt formalize this discussion in the months to come — but some mighty wide-awake thinking also goes on off-stage.

In an attempt to garner these views, in a sort of Society-wide discussion-fest, IE made a survey of opinion, from all branches of the industry. Replies to this were vastly interesting. Speaking informally (dictated letters) and anonymously, the views, opinions and sound predictions brought forth make a valuable discussion of lighting and its future.

The discussions seem to cover several areas within the general subject of: the new recommended levels of illumination and what they may mean to future lighting practice. Very canny predictions are made regarding future trends in equipment design and/or lighting practice; the effect on such structural elements as air-conditioning, building, and design considerations, to name a few.

In some ways, the advent of higher footcandle levels has created as much consternation as when sound descended on the silent movies. It's to the good, of course, that thinking men view with alarm *any* possibility of "footcandle engineering." Over and over occurs the caution that *quality* with the new levels is more important than ever. Indeed, all comment seems to stress that the key to success of lighting practice is emphasis on visual comfort — with a trend to "pleasantness" as well. More complaints stem from glare, said one engineer, than from insufficient light!

"It Seems to Me"

• • • The new IES lighting levels, while ahead of general practice, are only level with, and in some cases behind current advanced practice. As advanced practice today is the current practice of tomorrow, I expect the new lighting levels to come into general use in due time.

Probably the reason for this is that the fundamental thing both Blackwell's and Weston's work illustrates is that if you want to see as well as you can, you need daylight levels. You can read text having a 2-minute of arc stroke, black on white background, at 90 per cent of the maximum possible rate, with 9 footcandles; at 95 per cent of the maximum possible rate with 22 footcandles; at 98 per cent of the maximum possible rate with 60 fc; and at the maximum rate with 600 footcandles. That is, if you want that degree of certainty of perception which is complete, you need a "daylight" level.

While people do not consciously know this, their bodies do. Their bodies respond so favorably as lighting levels go up, and people feel such refreshing certitude in their perceptions, orientation and actions as lighting levels go up, that they will continue to adopt higher levels as fast as they can afford to; up to the point that they can afford to introduce daylight levels indoors.

This rise will be accompanied by changes in both light sources and equipment. Nothing necessarily revolutionary, but a tendency to more highly loaded fluorescent lamps, and any other way, such as high voltage and high frequency systems, that will produce more light for less power.

Higher brightnesses will require sharper control. This means the area of the lighting equipment will grow larger — occupying a greater percentage of the field of view, but with less and less light sent directly towards the eyes, the higher the levels go. This will be accomplished by more accurately designed louver systems with shielding up to 80 degrees from the horizontal, and more complex lens system controls.

Air-conditioning is affected by present lighting levels. The higher the level, the greater the Btu's released, and the greater the refrigeration required. Therefore, higher levels will require more air-conditioning in summer, or in all year round warm climates. Partially offsetting this will be more use of rapid air movement, as lighting levels rise.

A person indoors is likely to feel uncomfortable with an illumination of 125 fc at forehead height from incandescent lighting, or 600 fc from fluorescent, owing to the infrared component. He would not feel uncomfortable outdoors with these levels because of the normal rates of air movement outdoors. We will have to begin to introduce air movement indoors at rates approaching comfortable outdoor rates. So there should be considerable development of more advanced ventilating practice.

Higher levels will also affect heating practice. All the wattage consumed by lighting units ends up as useable Btu's of heat input, and will be taken into account in building design as lighting levels rise. A 100 fc incandescent job, or a 500 fc fluorescent job, is practically a complete heating system. Methods will be developed to save on central heating costs in many cases by using the heat by-product from good lighting jobs. This will help to make higher lighting levels cost less; and perhaps less than the lower levels of today where the heat by-product is not enough to permit economies in building design and separate heating expense.

• • • I suppose, in a way, the architectural profession has been endeavoring, without knowing it, to get enough light inside buildings by encasing them entirely in glass. They are reluctant to put in the electrical equipment necessary to get such levels, but I doubt if the result from the inside is very comfortable for the occupants of these "glass houses." The heat in itself becomes a sizable problem, and air-conditioning again calls for a readjustment of economic factors in the building. This may put a limit to the amount of the new lighting recommended that will actually be installed.

New buildings designed by some of the younger and more daring architects, and for clients who want the publicity for their modernity and care less about the economics, will undoubtedly be the first to apply the new lighting levels. For existing buildings it will be much slower because of the rewiring needed, the difficulty of adapting present fixtures to the problem, etc.

• • • Frankly, I consider the greater emphasis now being placed on *task illumination* of more importance than the footcandle levels themselves. Sometimes our enthusiastic sponsors of the new higher levels forget that these apply to tasks, not to areas.

The outstanding thing, as I see it, about Dr. Blackwell's researches has been his avoidance of the conditions which limited previous researches, together with his "non-commercial" willingness to go the limit. Commercial interest frequently limits one even more than it stimulates him because it prevents a frank specification of all that a task requires. The researches themselves established what seem like remarkably high levels as being needed for certain tasks. This might well have been expected, however, by anyone who has followed the evolution of lighting practice throughout recent years.

Following this matter of task illumination further, it seems to me that an honest application of the new knowledge must influence lighting practice through the need for adapting the lighting to the task. No longer will average illumination throughout an area be inherently satisfactory, although that level may be uniform where the tasks are closely distributed. Again, our past conception of maintenance factor is out the window, whatever these two revised conceptions may do to our standard design procedures. In this general connection, it seems to me we must expect a non-uniform distribution of lighting equipment to obtain a uniform distribution of illumination in such places as classrooms.

• • • My remarks concern mainly industrial, office and school lighting. Rather obviously, some changes will be required in fixture design. With the new levels, considerably more care in design will be required to produce comfortable lighting systems, free from direct and reflected glare. Many currently used types will be impractical. As levels are raised, brightness ratios become more critical. High reflectances will be a must in office interiors, and floor reflectances of 30 per cent to 50 per cent will be the order. We will have to pay particular attention to the interior decorating of the rooms, to relieve monotony but still not have unbalanced brightness ratios. The psychophysiological effects of large, blank areas of wall and ceiling will become important. Color coordination will also be more important, with the installation of higher levels.

It seems to me that lighting systems must necessarily go to larger areas of lower relative brightness, such as indirect lighting, luminous ceilings, and large area luminaires. Shielding will be desirable, and often necessary, on large area sources such as luminous ceilings. Direc-

tional materials in such ceilings will be more in the picture, I think, particularly if used in a manner that does not produce reflected glare. If electroluminescence achieves a practical efficiency, then luminous walls might be used to supplement ceiling illumination and achieve good brightness ratios, particularly for rooms with large window areas.

I don't visualize too much change in industrial lighting except that larger percentages of uplight and better shielding will be desirable, with higher levels. Unfortunately, unless the public's lighting education proceeds faster than heretofore, the same general types will probably be used for levels of 300 or 400 footcandles! Contrary to some opinions, I believe that most industrial high-level lighting will be by means of general rather than supplementary lighting. My experience has been that the maintenance problems raised by supplemental lighting are too great to encourage its use.

Maybe some of our current recommendations, calling for extremely high intensities, will trigger some research into the proper *type* of lighting — to accentuate recognition features of tasks. Such as oblique angle lighting, color control.

Light sources of higher output and higher efficiency must necessarily be developed. For most current recommendations, sources now existing will serve (if the ballast noise problem can be solved) but in many cases the penalties of cost of fixture required to do a proper job will be a deterrent. A practical, high-efficiency area source is needed. Maybe the new square fluorescent lamps are on the right track. Acoustical properties of a lighting system will become pretty important as sound control by conventional materials becomes confined to the walls and floor.

One thing you can bet on is that there will be a large number of sour high level jobs in the next year or so. I am very unhappy about this possibility — a poor job at 200 fc is far worse than a poor one at 50 fc. I just hope there aren't enough such jobs to discredit the cause of the recommended levels and set us back several years.

Whatever we do in our discussions of the new recommendations, we should take care to avoid giving the impression that this is the last word. Since research into the application of Blackwell's findings is proceeding, and has already resulted in the revision of thinking on the field factors to be applied for tasks of differing informational content and required speed of visual performance, it should be stressed that this is the latest; it is a start in the right direction; but by no means is it the final answer.

* * * To state it plainly, I believe that the lighting industry was quite unprepared for this great forward step. It has been "caught napping." Being a firm supporter of the new IES recommended illumination levels, I have officially advocated full and immediate adoption of these standards for those who plan and thus shape future building. But I meet with diverse reactions and honest questions.

"Fixtures" as we know them today do not appear to lend themselves to the new quantity-quality lighting. We know that new light sources are not developed over night and thus we should, for the time being, have to work with those we have. On the whole, existing light sources cannot be put into the great majority of existing fixtures and produce the type and magnitude of illumination we are now talking about. Furthermore the trend we set in lighting design, equipment, etc., will have to carry us through to the next upward revision in footcandle levels once we move toward acceptance of the 8 or 10 APS's (which must eventually come).

The new techniques must, of real necessity, be worked out in close cooperation with the acoustical and heating-air-conditioning engineers. It makes little sense to try to overcome one deficiency (in seeing) while ignoring the other comfort factors of heating and breathing and general existence. We need to consider all these factors together and not separately, as if they were isolated factors. They are not!

In regard to the extent to which present interior illumination meets the new standards, I would say that we have already seen good beginnings in some of the overall luminous ceiling designs. Many of these could increase their illumination by simple changes in auxiliary equipment. Others, especially the open or louver-type ceilings, have already been designed with no regard to reflected or even direct glare. Much more must be known and widely published before we can halt a trend toward quantity *without* quality in lighting.

* * * Just how "high" do we mean when we say "higher levels"? Some areas, of course, are shown to require in the neighborhood of 200, 300, 500 and 1000 footcandles. But these are all for visual tasks of considerable difficulty. Even in factories the great mass of footcandle values are for 30, 50, 70 and 100. In offices the recommendations are for 100 to 150 fc, with only detailed drafting going higher. In cases where 500 or more footcandles are recommended, it is for highly specialized seeing tasks rated as *very difficult* or *most difficult*. These usually turn out to be seeing tasks over relatively limited areas, such as inspection work or fine machining work in factories, or feature displays in stores, for example. Values such as these are not recommended for general lighting throughout a building, or even throughout an entire floor. By and large, we are talking about 150 fc and below.

Certainly lighting levels in this area are practicable and desirable. In fact, many customers have been *asking* for them, for some time. Many good jobs have been bought, not sold! In addition to meeting IES recommended levels, however, a good lighting system must, in my opinion, check for six other factors:

They must be *efficient* systems that are *visually comfortable;* systems which have *good appearance*, and harmonize with their surroundings; systems that operate *without trouble*, that are *easy to clean and relamp;* and finally systems that provide the customer with the benefits he wants, at a *reasonable cost*.

There's nothing new about these six factors, of course. We're all very familiar with them. But for higher levels to be an immediate practical fact, we should be prepared to go into detail on each of these points, for every job we install.

* * * Many people consider the new recommended illumination levels as being radical — something entirely new. Actually, they only validate some of the earlier thinking of Luckiesh, Harrison, Logan, Moss, and many others. However, they do furnish us with proof of *why* these levels of illumination are needed. We have known for a long time that higher levels were necessary. People have been trying for years to use the higher levels, with natural light, to accomplish various tasks.

For years men and women have taken an article of clothing or a piece of unfinished cloth to the front door of a store, to determine its quality.

For decades the watch repairman in the jewelry store has worked in the front window to see his work.

As long as we can recall, people doing critical inspection work in industry were given the choice locations next to outside windows. Many times this natural light was inadequate and work had to be temporarily suspended.

Theatrical people have used the increasingly efficient light sources as fast as they were developed and have used extremely high levels at the critical points of interest involved in a stage performance. A good theatre lighting

man, whether he realized it or not, has established a desirable contrasting effect between the subject and the background or surround that automatically accomplished some of our desirable conditions for ease of seeing that IES is advocating at the present time.

The new revised illumination tables not only tell us we need increased illumination but suggest how much we need, as proved by long-term scientific research experiments.

* * * In our work as lighting consultants we not only assist architects and engineers in the design of new installations and relighting, but we also are called by many store owners, offices etc., who have a problem with their lighting. A large percentage of the complaints we investigate have been caused by glare, both direct and indirect, and very seldom are they from insufficient light. The glare may be from a fixture which is too bright, or from one which has too high a brightness contrast with its surroundings. Generally, though, such complaints result from reflected glare caused by a lumi naire improperly placed, directing light from the wro ng direction. By this I mean a higher incident of light from the front than from the side or back. In order to perform a critical seeing task, whether in office, factory, school or home, minimizing glare is fully as important as having a high level of illumination.

We hope fixture designers will provide luminaires which conform to the brightness limits established by the office lighting committee, because as the levels are increased, glare must be ever more carefully controlled. As far as light sources go, we are inclined to believe that there are already higher-output sources available than we know how to control.

The most urgent need, we feel, is for the application of those techniques of lighting design which produce comfortable seeing conditions. If we sell higher levels without due regard to

control of fixture brightness,
orientation of fixtures with respect to direction of vision for critical seeing tasks,
use of lighter colors and lower contrast of surrounding environments,

then unsatisfactory results are going to occur. This will delay for many years the acceptance by the general public of the higher levels which they need and someday will have with comfort.

* * * I have ever been an advocate of control of reflected brightness as compared to the appraisal and control of direct brightness and I am very certain that this will come more and more to the front as we produce higher levels of illumination. This, of course, gets around to the problem of the trend in lighting systems and I have already been working on the integration of the troffer systems with low brightness lens in luminous ceilings which seems to be the practical approach in commercial structures where not too much head room is provided because of the effort to reduce cubage in such projects. Of course, in higher ceilings suspended fixtures with a direct and indirect component, with the direct component again equipped with control from low brightness lens, offer another satisfactory solution. Also, of course, there are the luminous or totally indirect systems where ceilings are sufficiently high, but I feel that we cannot obtain the high levels from either indirect systems or luminous ceilings systems alone. Some means of superimposing direct components seems to be mandatory and I have mentioned my concepts in connection with meeting such requirements.

* * * There are several things that *must* happen, and soon, with the application of the new IES levels. Luminaires, for one thing, need to be more esthetically pleasing and more integrated into the interior design. Furthermore, brightness of luminaires must be more carefully controlled, and kept within an appropriate comfort range.

As one prediction, I think that individual fixtures of small size will give way to larger luminaries whose size will make them architectural elements.

As another, I think that lighting systems will need to be designed to produce specific brightness patterns in the field of view rather than being designed only on a uniform footcandle basis. Greater attention will need to be paid to the directional quality of the lighting and its effect upon specific seeing task situations. Localized lighting with illumination levels in the thousand footcandle region will be common. Such levels will be superimposed on general levels of hundreds of footcandles.

There seems to be no question but that lighting systems will be used to produce heat as well as light, thus minimizing the requirements for a heating system. In this case, higher footcandles than now used will be a desired by-product. Lower cost of electrical power will accelerate this type of combination system, especially, perhaps, in the northern part of the country.

Lighting systems of the future must be designed to have less maintenance. Filtered air conditioning has helped a lot in this respect. Expensive maintenance is a serious deterrent to good lighting.

In general, it seems to me, the acceptance of the new levels will depend directly on how well the engineers design the pace-setting installations. If these are comfortable and pleasing, as well as meeting the new footcandle recommendations, there's no question in my mind that people will continue to ask for more light when future jobs are planned.

* * * As to techniques of lighting practice, we feel that there will have to be changes because the brightnesses will be much more critical with these higher levels. We may have to formulate brightness contrast tables to coordinate with the higher footcandle levels as to our definition of comfort.

Regarding interior design, the architect may have to consider these architectural luminous elements (large area systems) and put design around the unit into his basic design when obtaining a concept of the room proportion and function.

* * * Referring mainly to the school and office lighting fields, some present luminaire designs appear to satisfactorily provide the recommended new levels. However, new designs will largely be required if the new footcandle levels are to be obtained with proper quality of lighting. New designs will be needed to accommodate the higher-output lamps and to limit brightnesses.

Higher levels will require more attention than ever to brightnesses in the field of view, if visual comfort is to be obtained. The reason for this is that the upper range of comfortable brightness above the adaptation level decreases as the adaptation level increases.

Higher-output lamps will be useful in providing more footcandles, but they do bring problems as far as commercial luminaires are concerned. One problem is the necessity of avoiding excessive lamp temperatures and the dissipation of more ballast heat. Another problem is noise. Certainly present ballasts for 1500 ma lamps are too noisy for use in schools and offices without some special treatment to reduce noise from the ballasts. Luminaire designers expect that ballast manufacturers will eventually provide quiet ballasts for use with the higher output lamps.

As for trends in lighting systems, I believe it will be toward large-area luminaires and luminous ceilings. This appears to be one way of obtaining higher footcandles with comfortable brightnesses. Such a trend should result in a

closer tie-in between the lighting engineer and the interior designer or architect. This would be to the good — each needs a better appreciation of the other's aims and objectives.

A trend has already started to combine luminaires with air-conditioning exhaust and input openings. This has one decided advantage in that it combines two systems that often conflict with each other for location and space. I don't know whether there will be any complications in this by involving more than one trade.

Higher levels will increase the cooling load for air-conditioning, certainly. This is looked upon as a serious factor by some engineers but I do not think it will have much effect on the adoption of the new footcandle levels. The advantages to be gained from the higher footcandles far out-weigh the additional operating costs of both the lighting and the air-conditioning. Also, the higher footcandles represent progress in lighting, and I think it is quite evident that progress, whether it is in lighting, transportation or any other field, will continue in spite of what presently may appear to be obstacles.

* * * To get the new recommended levels comfortably, fixtures might be designed with a combination of materials such as luminous panels, or small-celled luminous louvers to diffuse the light sources, and baffled by some form of acoustical and thermal wedges or baffles. The thermal or acoustical baffling might be of an Alzak finish which would be integrated with a ventilating system that would take the hot ambient air around the lamps and transfer it into the room area during the winter months. In the summer months it could extract the hot air from the office area and also the upper plenum area into a duct to be exhausted from the building.

In present louverall ceilings it is quite possible to increase illumination levels to 200-plus footcandles without any apparent brightness discomfort. This may be accomplished by installing higher lumen output lamps and shielding the lamps with plastic or diffusing mediums dropped below the lamp several inches and above the louverall ceiling, thus diffusing the brightness of the source on the louvers.

The combination of the luminous and baffled louvers should be designed to provide an average brightness not to exceed 100 footlamberts at 200 fc. We can have higher footcandles with the accompanying brightness control limitations that will provide for visual comfort. As a prediction in the trends of lighting systems, floating ceiling units in modules of 4 ft by 6 ft or 4 ft by 8 ft, etc., prewired, that can be ganged together to form any size ceiling have excellent potential. It is important, however, that in large area illumination design, wall to wall ceilings, or floating ceilings, be planned for close end wall and side wall spacing — 6 inches to a foot and not to exceed two feet.

* * * In re future "fixture" design — don't we really mean luminaire design? I make the distinction because there is the mechanical and electrical part of the luminaire which is sometimes called a fitting or a fixture and which may not see a great deal of change because of these new footcandle levels, although there are changes which are dictated by other considerations.

Unfortunately too many of our brethren in the business limit their design consideration to just this. I and my company are very seriously concerned with the performance of the optical design and here there are most definitely changes that must come. They will require a higher degree of skill and engineering than that which is now generally available. The whole luminaire design will be affected and this will in turn make it possible to develop new techniques of lighting practice, light sources, etc. Of course this process works in reverse too and it is a very interesting phenomenon.

Lighting systems will change and so will interior design because the whole interior will be designed by the professional illuminating engineer. At least if he doesn't do it he will be considered because the size of the light sources, the location of them, the placement of the furniture and the finishes, will all play such an important part that the illuminating engineer will have to be given increased consideration.

* * * Contrary to what lighting sales books and courses continue to tell us, our main concern today is not how to install higher levels as much as it is to direct our clients toward the proper type of lighting equipment. There seems to be considerable confusion as to whether present lighting units will be adequate to handle increased levels. The engineers are waiting for the manufacturers to tell them, and the manufacturers are confused because of local code restrictions and Underwriters' limitation on high-output equipment. My personal guess is that fixture design will be the biggest single factor that will slow down an all-out application of the new higher levels.

* * * In my opinion this (higher fc) will bring on a trend toward greater use of area illumination. Since there has been a distinct trend in this direction, the higher levels will result in an accelerated acceptance of this system. This in turn will have some effect on interior design. There will be a greater need than ever, in this event, for close coordination between the interior designer, the architect and the illuminating engineer.

With higher levels of illumination, accumulations of dust and grime become more apparent, which may require increased maintenance. Flaws and defects also become more apparent, and this could possibly create a need for early replacement of furniture, rugs and other equipment.

* * * I have said for some time that I feel the present trend will be towards area illumination rather than individual fixtures. Most certainly, we can expect to see more panels of light rather than expansion of the luminous ceiling idea. We have seen quite a growth of the so-called integrated ceiling in this area, and I definitely feel that as far as commercial buildings are concerned this trend is going to continue. Eventually there will be a prefabricated ceiling which has acoustical values, and the lighting and air distribution system will be built as an integral part of the ceiling.

* * * It is difficult to predict a trend, but to try: The future trend will be in large-area lighting equipment, both direct and indirect. Much more attention will go into illuminating and illuminated walls, curtains, etc. Much more effort will go into controlling illumination directionally, brightness, contrast, etc. Many systems will be designed with no set amount of illumination but will be flexible systems in which the amount of illumination will adjust to the task and requirement of the environment.

* * * It is hoped that high-frequency fluorescent lighting systems will be developed that will be flexible and of relatively low cost. Such developments, along with new fixture designs, would hasten wide acceptance of high-level lighting in commercial areas.

* * * Although there is some excellent equipment available today that enables us to provide high levels comfortably, there is definitely a need for other new designs that will give us greater flexibility and economy. Some of our old stand-

bys just won't be applicable, although I suppose that some people will try to misapply them, and will get burned in the attempt.

Other old standbys such as troffers are going to provide better lighting at the higher levels than they provided in the 50-fc range. I say this because troffers have often been spaced too far apart, with too many lamps in each troffer. This has resulted in excessive shadows, too great an expanse of relatively dark ceiling, and too much brightness difference between the troffers and the ceiling. To obtain the higher illumination levels, troffers must be spaced closer together, thereby reducing the expanse of ceiling and minimizing shadows. The ceiling brightness will be increased in direct proportion to the increase in illumination level, assuming all reflecting surfaces in the room to be unchanged.

In the new equipment design area, I think we are starting to see and will see even more large-area lighting elements with a variety of shielding and lampings to obtain different levels. I firmly believe, too, that we will see increasing use of aluminum reflectors with the more highly loaded fluorescent lamps. This will be necessary to control the high brightness of these lamps, and such equipment that is now available is becoming increasingly popular. This use of aluminum applies to both industrial and commercial interiors.

* * * Wide acceptance of any given state of lighting practice is dependent to a great extent on the availability of lighting equipment and lamps that afford *economical* installations — at or near the relative low point of total annual operating cost. Presently this is not the situation for all areas of lighting. In fact, the only area reasonably prepared, fixture-wise, for the new recommended lighting levels is that of the industrial general lighting market.

Much work, in general, must be done with fixture designs to handle the new higher-output fluorescent lamps to provide higher lighting levels with increased comfort and improved seeing conditions. Any future trend in lighting practice *must* be toward creating a comfortable visual environment. The key to successful new lighting installations of current levels will be quality. Quality will be the keynote in the future, with quantity of light as an important aspect. Any other approach to the situation will create problems which will take the lighting industry a long time to overcome — and will deter the acceptance of the new levels.

* * * New levels put into practice will lead to the development of more large-area ceiling fixtures equipped with several fluorescent lamps to provide greater lumen output per luminaire at reasonably low fixture brightness. These will not be confined only to rectangular or square-shaped designs as we now see them. I predict that future large-area luminaires will tend to artistic shapes like ovals, kidneys, etc., to impart more decor to the room.

Because of certain performance problems associated with extra-high-ouput fluorescent lamps (1500 ma) I doubt if lamps with even higher outputs will be introduced. However, the trend may go in the direction of U-bent, L-bent, or even V-bent shapes of standard 425 ma fluorescent lamps, for better light distribution in large-area luminaire designs.

Obviously, larger and more costly air-conditioning systems will be required to handle the additional heat generated by multi-lamp luminaires to provide higher footcandles. However, it is my opinion that room air-conditioning will be supplemented by a forced air ventilating system designed to take the heat from luminaires and ballasts. In some cases, ballasts may be located in some convenient room that is ventilated. Luminaire ventilation may be achieved from auxiliary air ducted above the ceiling (where ceilings are furred down for other utilities).

From observation, it is obvious that during the past few years such places as modern supermarkets, urban shopping centers and modernized chain stores have installed high levels of lighting to attract customers. The levels in most of these places fall within the higher footcandle range — primarily because their owners recognize good lighting as a merchandising essential.

* * * Phosphors aren't the only materials that have characteristics of excitation in the field of energy conversion. Light sources in the future may be developed in new forms as other materials are applied to this service. Lamps of superior efficiency that depreciate very slowly, with corresponding reduction of maintenance, are on the way now. Easier lamp starting for fluorescent types will come to advance this expectation. Frequent starting, therefore, will have less effect on lamp life. This development may make fluorescent lamps more widely popular for home use.

* * * Due to the higher efficiency and lower installed cost of the high-output light sources, including the 1.5-ampere (and perhaps 3-ampere), different techniques of the application of light are becoming evident. In working with the higher output sources under low ceiling conditions of modern architecture, they must be applied so that glare is controlled both from the direct and reflected standpoints. We feel that this indicates a semi-indirect system with controlled brightness in the 0 to 45-degree zone as well as the 45 to 90.

In general, we can envision approximately twice the watts per square foot, in some instances. This would affect air-conditioning and electrical distribution systems. In actual commercial practice, however, the higher footcandles referred to as "new levels" have been in practice for some time. Most of the better jobs that have been properly engineered in the last few years have been in the range of the "new levels."

It is my feeling that the "new levels" will be most effective in such places as public institutions, schools and so forth, where the executive authorizing these expenditures needs justification for his stand. The present levels published by IES and ASA would not give this background where it was needed. Most commercial and industrial users of light, who do not need this type of backing, and can use their own judgment based on financial returns from the capital investment, have already progressed beyond the present footcandle levels.

* * * Lamp manufacturers each year have come forth with newer light sources of greater efficiency from a strictly physical standpoint of lumens per watt. They have been justifiably proud of such achievements. However, in each case these developments have provided a number of corollary problems that the fixture manufacturers have not yet caught up with. These run a whole gamut from wiring capacity of existing buildings, dissipation of heat in a safe manner, adequate control of brightness and brightness ratios, maintenance, high labor costs and finally, the relative economy of the whole thing.

That's why I say that a great responsibility goes with the new lighting levels — the responsibility of producing *comfortable* means of providing them.

* * * In my opinion, industry will be the first to universally accept higher levels. They know the benefits of higher levels today, and anything to increase production, reduce accidents and create a better worker morale will be desired — aiming

to increase production and reduce cost of the commodity being manufactured.

Commercial establishments will probably gradually improve their illumination as the competitive field becomes increasingly acute. I am not so sure but that the mercury light source with a more compatible color rendition will be used increasingly in offices, stores and other places where a higher levels of general illumination will be desired, and are obtained from above-the-ceiling light sources.

Large business offices will undoubtedly step up levels considerably, but the rental office building as we know it will be slow to increase illumination, except when forced to do so by an interested prospective client.

* * * Illumination technology is far in advance of lighting application techniques. It is my estimate that at least 75 per cent of all stores and offices, schools and industrial plants are under 50 fc. Unless the illumination industry makes better use of application data published by IES and other interested groups, we will be many years trying to reach 50 fc of illumination. The lighting industry has a long upward pull to meet the 50 fc level established some years ago, before it can begin applying these new higher levels across the board to commercial, industrial, institutional and school lighting categories.

* * * Opportunities today are greater than ever for creating attractive, efficient working environments. I am speaking particularly of offices, but this can apply in many other areas. One practical approach is through coordination of the physical facilities of a space into a total environment that is pleasant and stimulating to the eye. At the same time there are possibilities for effecting economies when real integration of the visual, sonic, and thermal aspects of the environment is achieved.

The coordination of lighting and air-conditioning, in particular, has much to offer in commercial and industrial areas. Attainment of the new illumination standards means that lighting can become the principal source of heat for a building during the cool months. This is an asset too often overlooked in the concern for cooling requirements during the warm months of the year. (Actually, solar load is still the greatest factor in determining design capacity for air cooling in buildings which have appreciable areas of glass walls — say 30 per cent in glass, or more).

However, since much of the electric energy input to a fluorescent light source is converted to long-wave conduction and convection heat (45 per cent) and since part of the radiant energy output is absorbed and converted to longer wave energy as determined by luminaire efficiency, there is an opportunity to remove much of the heat load from the luminaire before it heats the air in the occupied space and requires additional air cooling.

Such techniques as ventilated ceiling cavities, ventilated luminaires and liquid cooled ceiling systems are being employed. Testing and experimentation are under way in several areas to reveal the possibilities of such schemes and document their performance as an aid to the design of future systems. Preliminary data indicate up to one-half the heat load from lighting can be removed before it heats the air in the occupied space. Reports of some of these tests will be forthcoming later this year. True integration of all the aspects of an environment can not only provide more satisfactory results, but effect economies in construction as well.

* * * The relationship of lighting and air-conditioning is becoming a tremendous problem from at least two standpoints. First of all, the wattage loads being introduced into areas for lighting alone are beginning to tax severely the ability of the air-conditioning engineers to remove, economically, the heat generated, without allocating excessive space for their equipment. At the same time that we are creating the need for more air-conditioning with its ducts and diffuser outlets, we are filling a greater percentage of the ceiling space with lighting equipment. This has already led to the marriage of lighting and air-conditioning by several manufacturers. But there are various problems which are far from being solved.

* * * Insofar as air-conditioning is concerned (with higher lighting levels) ballast losses, and in many cases the actual radiant heat of the fixtures, will have to be dissipated without allowing it to reach the air-conditioned space. At present almost 40 to 50 per cent of the total air-conditioning load in our modern buildings is used up by the illumination system. Something must be done to reduce this total load insofar as it affects the building space. This may mean remoting ballasts or the use of some system of high frequency where the frequency converters are remote from the air-conditioned space.

* * * Concerning air-conditioning, this depends on where the ballasts are located. If in the immediate area, more air-conditioning will be required, which could mean the lighting equipment might also be a part of this system. If ballasting is remote it will not bother the design of the air-conditioning to any great extent.

* * * The effect of new lighting levels on air-conditioning, and vice versa, is a subject that has many considerations. It seems to me that in commercial areas such as stores and offices, the installation of the lighting levels recommended for these areas and the installation of air-conditioning will have to be a package. Where air-conditioning is already in, the situation could be complicated. Air-conditioning modifications required with relighting, and the cost of same, is an angle which needs some working out.

* * * Within the normal uses of the new light levels, say for bookkeeping and regular office work, I don't think that the air-conditioning presents too serious a problem. We've been operating between 100 and 120 fc in our open offices for twelve years. Some supply increase in the air-conditioning capacity was necessary but I've never heard of this being a major consideration to our management. Of course, when one gets into 200 fc and upward, then air-conditioning does become a factor. The problem may be more acute in older air-conditioned buildings where there may be difficulties in enlarging the cooling capacities. People have become accustomed, in renting offices, to demand air-conditioning, whereas they are lax in demanding the amounts of illumination that should be required to eliminate mistakes, three o'clock headaches, etc.

* * * Values of 200 footcandles and up for general application appear frequently in the new footcandle tables. These values must presuppose air-conditioning. For rooms with 150 fc or more, we may expect the heating requirements to be met in part at least by the lighting system. Light and heat at the flick of a switch is easily within expectation for the future.

With this heating-with-lighting system, room design may tend toward lower ceilings, reduced cubage and more economy in the operation of air-conditioning equipment. Well ventilated luminaires (that are connected with ducts for outdoor heat removal) will offer us far more flexibility in designing facilities for

health and comfort in buildings of the future.

Before these developments can be widely realized though, a much more thorough education about lighting appears to be needed, even by people in the lighting field. Not too many people today really understand the potentials of lighting. Those of us who make all or part of our living in lighting need to get better acquainted with the opportunities.

* * * Increasing levels of illumination will naturally have an effect on the air-conditioning load. This increase, of necessity, must be taken into consideration when figuring out cost studies. Heat education will be of prime importance with the trend toward built-in lighting effects. Ballast heating will become a major factor. Architects and design engineers will have to be educated into the limitations of the fluorescent ballast.

* * * Greatly increased footcandle levels bring about a greatly increased production of Btu's. This, of course, has a marked effect not only on the initial cost of air-conditioning systems but also on the design of these systems. Our own new home office building consists of 23 floors with 15,000 square feet per floor. It was laid out for "current lighting practices" just prior to the release of the new footcandle levels. I hasten to add that the current practices which were used on the original layout were well in excess of the then existing IES recommended practices. It, of course, has subsequently been re-designed to incorporate the new footcandle levels.

Having made two plans, we obtained electrical contracting prices for both plans. The additional footcandles made necessary 40 additional tons of air-conditioning, and such additional luminaires and wiring capacity to cost a difference of $500,000 between the two bids. I am happy to report we chose the new standards.

The most interesting feature of this, our first large application of the new footcandle levels, however, lies in the design differences of the air duct system used for heating and cooling. We found that the new lighting levels produced more than enough heat to heat the building on a ten-above-zero day. Plus ten degrees is the design temperature for heating installations in our city.

The perimeter offices will need heat on severely cold days, whereas the centrally located offices will need air-conditioning on these same days. Our current thinking is that we will use recessed troffers in continuous rows on six-foot centers with these troffers serving as air ducts for conducting the ballast and lamp heat from the air conditioned areas over to the areas needing heat. Since the lighting system is being used as the source of heat for the heating system, it will be necessary to have the lighting system on thermostats through the night in order that the building will not become excessively chilled during a cold night.

You can see, therefore, that the new footcandle levels are rapidly bringing about extremely interesting design procedures since in this case, it is directly linked with the building heating through thermostatic control.

It goes without saying that the 200 footcandles applied dictates a rather rigid control of reflection factors for virtually everything in the office. When troffers are used as air ducts, the interior design is improved in appearance because it eliminates anemostats and air diffusers from spoiling the appearance of an otherwise beautiful ceiling.

* * * It is unavoidable, and exceedingly proper, that users of light as of everything else, will weigh its advantages against its cost (including in the case of higher lighting levels both the increased and decreased cost of air-conditioning). Advocates of proper lighting must be ready to meet such reactions with facts, but they should first establish the values or benefits against which that cost is to be applied. In other words, the fact that the new lighting is low in cost relative to other things is not an adequate reason for its use.

* * * There is a definite tendency toward lower ceiling heights in new buildings these days. At the same time, air-conditioning installations in all types of construction still further minimize the space adequacy for appropriate recessed lighting equipment. Up to the present moment, illumination has still failed to capture enough of the public fancy to put lighting on the same level of desirability as air-conditioning. This is a very sad reflection on our profession and industry. The result has been that lighting is too often sacrificed so that other necessities can be achieved. It gets back to the point that so far we have fallen flat on our face in selling the public at large, and many specifiers, on the true story of lighting.

Conference Papers to Discuss Factors Related to Current Practice

Among the papers scheduled for presentation at the National Technical Conference, in San Francisco, this September, are several related to factors arising with the new recommended levels of illumination. They are on such topics as: luminaire design, air-conditioning and improvements in light sources for higher lumen output.

Mercury and Fluorescent Team-up For Industry

By MORGAN CHRISTENSEN
QUENTIN D. DOBRAS

INDUSTRIAL plant management is more safety conscious today than ever before. Safety records are continually being improved, and lighting has been a major factor contributing to this achievement. Yet there is one area of change in lighting that can prove detrimental to the goal of accident reduction and that is the trend toward lighting systems using only mercury lamps.

Combining other sources with mercury lamps has been common practice in order to fulfill two basic requirements. The first is to improve color rendition of the bluish-green mercury light by adding a source rich in red light. The second requirement is to provide stand-by lighting in the event of a power interruption, even a momentary one.

The need for color improvement has been minimized by the development of improved-color mercury lamps. The need for stand-by lighting has likewise been minimized by improvements in the reliability and design of distribution systems. In almost any area, and particularly those with rotating equipment, a power interruption of only a few cycles can create a serious hazardous condition. Therefore, the need still exists for additional light sources which restart instantly when the power is restored.

Filament lamps have been widely used in combination systems with mercury to fulfill these requirements. However, a combination of fluorescent and mercury lamps offers several unique advantages. Either fluorescent or filament lamps can provide stand-by protection and improved color quality. But fluorescent lamps have an added advantage of compatibility with mercury in regard to voltage requirements, lamp life and efficiency. The newer higher wattage fluorescent lamps are compatible in light output as well. The result of these advantages is lower over-all cost of light for fluorescent and mercury lighting systems than any other combination.

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 17-22, 1958, Toronto, Ont.
AUTHORS: Large Lamp Department, General Electric Co., Cleveland, Ohio.

Distribution Systems

The steadily increasing electrical requirements of modern industrial plants have necessitated the use of higher voltages to supply this additional power economically. As lighting levels increase, the lighting load becomes an important part of the total plant electrical load. By operating the lighting and other electrical equipment at higher voltages, savings of 40 per cent or more have been realized in many instances. These savings have been recognized to the extent that already about 50 per cent of all new mercury lighting is operated at 240-480 volts.

Until the introduction of mercury and fluorescent lamps, the distribution voltage for lighting was usually in the 120-volt range. Filament lamps operate more efficiently and give better performance at 120 volts rather than at higher voltages. With mercury and fluorescent lamps, however, the ballast adjusts the input voltage to suit the lamp starting and operating voltage requirements. The ballast can be designed to accommodate a wide range of primary voltages without affecting lamp performance, but in general 480Y/277 volts is the best choice. Standard ballasts are available for both fluorescent and mercury lamps to operate on voltages up to 480.

Combination mercury systems may take several possible forms. One combines mercury and filament lamps on a 120/208Y-volt system. Another is a mercury and filament lamp combination with the mercury operated at 277 or 480 volts and a separate 120-volt system for the filament lamps. A third is a mercury and fluorescent system operated from a common 480Y/277-volt system. From a distribution cost standpoint, the third is by far the most economical choice. Fig. 1 shows the typical wiring diagrams for each of these systems.

Lamp Factors

Recent improvements in fluorescent lamps make them a much more desirable source for combination systems than ever before. Not only do they have

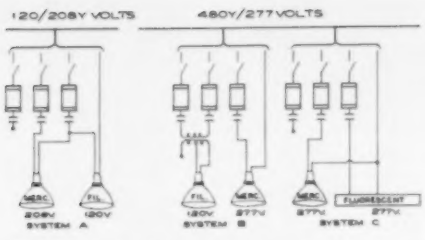


Figure 1. Typical wiring diagrams for three mercury combination systems.

lamp lives and efficiencies similar to mercury, but they now are comparable in light output as well.

For example, many combination systems use 1000-watt filament lamps and 400-watt mercuries. When this combination is used, the lamps can be installed on uniform spacing and provide nearly the same output. The same possibility exists with a 1500-ma high-output lamp. A two-lamp eight-foot luminaire provides somewhat more light than a 400-watt mercury and with longer life and greater efficiency than the filament lamps used in combination with mercury.

Table I shows the essential data for several lamp types which are typically used in these combination systems.

The similarity in lamp lives between fluorescent and mercury can have considerable effect on lighting maintenance costs. In some cases, it may be possible to use the same group relamping interval for both types of lamps. In general, fluorescent lamps in a typical installation will have about 20 per cent burnouts at 6000 hours which corresponds to the "economic life" of most mercury lamps. The simplified 80/20 per cent group relamping plan could be used with the fluorescent to determine the group relamping interval for the entire system.

The necessity for frequent replacement of filament lamps often makes maintenance difficult and costly. With the trend toward fewer filament lamps used in such systems, often a large percentage of outages are tolerated before lamp replacements are made. Fluorescent lamps, on the other hand, permit convenient relamping schedules and give greater assurance that stand-by lighting will be available if an emergency should arise.

TABLE I — Lamp Characteristics.

Lamp Type	Lumens	Watts	Life	Efficiency (lpw)[1]
FLUORESCENT				
F96T12/CW	5050	74	7500[2]	57
F96T12/CW/HO	7300	105	7500[2]	63
F96PG17/CW	13000	200	5000[5]	55
INCANDESCENT				
1000	23000	1000	1000	23
750R52	12700	750	2000	17[3]
MERCURY				
H400-EW1	23000	400	6000[5]	52
H400-J1	20000	400	6000[5]	45
H400-RC1	20500	400	6000[5]	47
H400-RW1	22000	400	6000[5]	50
H1000-RC15	53000	1000	6000[4]	48
H1000-RW15	55000	1000	6000[4]	50

[1] Includes loss in ballast.
[2] Average life based on three burning hours per start.
[3] Based on lumen output of processed lamp. Other figures should be multiplied by luminaire efficiency for direct comparison.
[4] Average life based on five burning hours per start.
[5] "Economic life" of the lamp under typical conditions of operation. Actual average life may be up to 50 per cent greater.

Economics

The selection of a lighting system in industry is usually made primarily on the relative economics of various systems. In addition, consideration must also be given to comfort, ease of maintenance and color quality, but all of these factors are usually balanced against cost.

To determine the relative cost of the proposed mercury and fluorescent combination a number of cost analyses were made. Because these cost studies showed that the (H400-RW1) mercury system provided the lowest over-all cost of light, it has been used as the base system in this paper. The relative comparisons using other mercury lamps would be similar.

Since the distribution system chosen has a marked influence on the total cost, three separate systems were used and are shown diagrammatically in Fig. 1. System A is a 120/208Y-volt three-phase system completely separated from the 480Y/277-volt power circuit. System B includes a 480Y/277-volt circuit for power and mercury lighting with 120 volts supplied from dry-type transformers for the filament lamps. System C is a 480Y/277-volt combined light and power distribution system.

The straight-line graphs shown in Figs. 2, 3, and 4 show relative initial, operating and over-all costs as the relative amount of mercury light varies from 100 to 0 per cent. All data are based on 4000 burning hours per year, 1¢ per kwh energy rate, and 10-year amortization of investment. The area analyzed is a large industrial plant with 4 bays, each 80 feet by 140 feet, and the lighting equipment is mounted at 44 feet.

The initial cost of the mercury-fluorescent combination is higher than the mercury-filament system. However, the high-output lamps have permitted a significant reduction over the older types of fluorescent lamps. For a combination in which mercury lamps supply 75 per cent of the total lumens, the (H400-RW1) mercury and high-output combination is only 12 per cent higher in initial cost than the (H400-RW1) mercury and

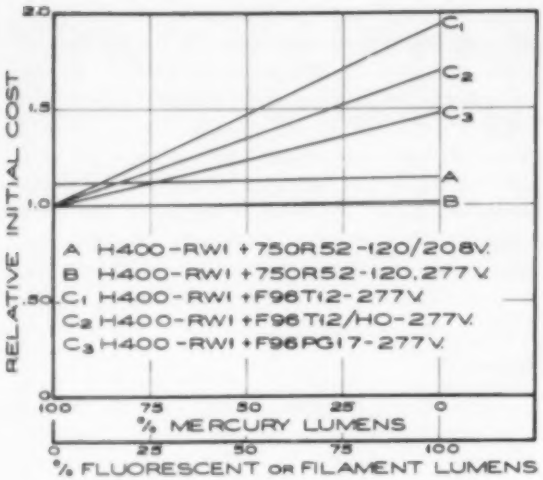


Figure 2. Relative initial costs for the mercury combination system.

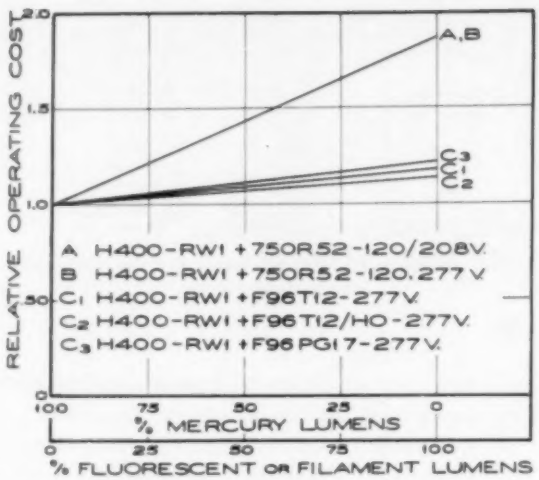


Figure 3. Relative operating costs for the mercury combination system.

(750R52) filament combination using System B and about equal in cost to the (H400-RW1) mercury and (750R52) filament combination using System A.

The operating costs for the mercury and fluorescent combinations are considerably lower than the mercury and filament combinations, as would be expected. For the same conditions as above, the mercury and fluorescent systems are about 17 per cent lower in annual operating cost.

Total annual costs of these same systems show that the most economical system is mercury lamps combined with the high-output (96T12/HO) or high-output (96PG17) non-circular cross-section fluorescent lamps. Putting this in easily applied terms, the typical total annual cost for a mercury and filament system, using System B with equal lumens supplied by each lamp type, is approximately 1.7¢ per footcandle per hour for 10,000 square feet of lighting. The same cost for a similar mercury-fluorescent system is 1.4¢. This saving applied to a large plant would amount to several thousand dollars each year.

Installations

Several plant owners have already recognized the advantages of combination mercury and fluorescent lighting and have installed such combinations in various types of areas. Four typical examples are shown in Figs. 5, 6, 7 and 8.

Fig. 5 shows an installation of the (96T12) slimline lamps with the improved-color (H400-RC1) mercury lamps. In this area, only enough fluorescent is used to provide the minimum amount of light for safety purposes in the event of a power interruption. Ten per cent of the light is provided by the fluorescent and the remainder by the mercury system. The lighting level is 50 footcandles.

Fig. 6 shows an installation where 25 per cent of the light is contributed by the (90T17) fluorescent units and the remainder by (H400-E1) mercury units. This installation has been installed for several years. The combination system provides 100 footcandles maintained in service with approximately 150 footcandles in those areas where seeing is more critical.

The comfort of many straight mercury systems can be markedly improved if fluorescent units having a substantial amount of upward light are added to the system. This upward light can

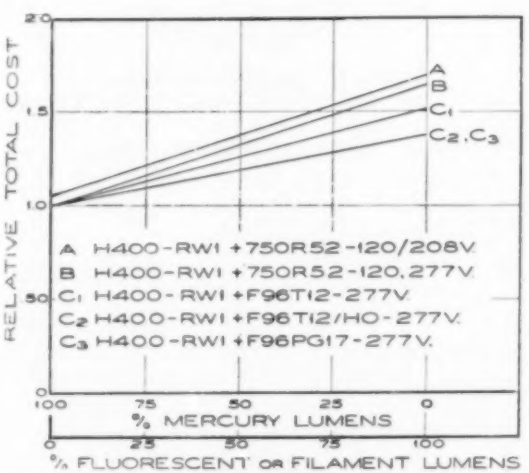


Figure 4. Relative total annual costs for the mercury combination system.

Figure 5. Ten per cent of the illumination in this area is provided by the (96T12) fluorescent system, and the balance of the 50 footcandles by the (H400RC1) mercury system. This is an example of using a fluorescent system to provide a minimum amount of illumination for safety purposes.

Figure 6. The (90T17) fluorescent system provides 25 per cent of the 100 footcandles in this installation that has been in for several years. This amount of fluorescent combined with the (H400-E1) mercury system supplies enough light for safety purposes and also for color improvement.

Figure 7. The illumination over the trackwell and decoiler area in this plant has been substantially increased by the addition of the (96T12) fluorescent lamps. The fluorescent system provides 70 per cent of the total light. The rest of the illumination is supplied by the (H1000-A15) mercury system.

Figure 8. The 1000-watt filament units in this area have been replaced by two-lamp (96PG17) high-output non-circular cross-section fluorescent luminaires. The fluorescent lamps plus the (H400-RC1) mercury lamps provide 70 footcandles. Changing from filament to fluorescent in this area increased the illumination level and at the same time decreased the amount of energy used.

brighten the ceiling and reduce the brightness contrast between the lighting equipment and its background. The newer types of industrial lighting equipment having an upward light component of 20 to 25 per cent are well suited for this purpose. If additional upward light is desired, the units could even be mounted upside down to increase the amount of upward light. This provides a relatively inexpensive method of bringing an existing lighting system up-to-date by improving visual comfort and increasing the lighting level.

Fig. 7 is an example of adding fluorescent units to an existing mercury system to increase the lighting level. In this case, 70 per cent of the light is provided by the 2-lamp (96T12) slimline units. The average lighting level maintained is 25 footcandles. The fluorescent units were added over a coiling machine and also over a railroad loading dock. The lighting level is somewhat higher in these areas.

Fig. 8 shows a very recent installation where the 1000-watt filament units were replaced by 2-lamp (96PG17) high-output units. The more efficient fluorescent lamps increased the lighting level and at the same time decreased the amount of electrical energy that was consumed. The plant engineer reports that the savings in energy will be sufficient to pay for the fluorescent installation in three years. Thirty-five per cent of the 70 footcandles in this area is provided by the fluorescent system and the remainder by the (H400-RC1) mercury system.

Conclusion

The advantages of a combination mercury and fluorescent system are numerous as outlined above. In general, such systems consume less power, are easier to maintain and are less costly to operate. New developments in mercury and fluorescent lamps should prove even more advantageous for this combination in the future.

The team of mercury and fluorescent will provide modern plants of today and the future with productive lighting. This team will also minimize accidents in two ways: first, through better seeing and second, by reversing the trend toward straight mercury systems.

DISCUSSION

N. B. Burroughs:* Another tool in the hands of engineers is the mercury-fluorescent team. This team furnishes an economically sound answer to industrial lighting problems. Both fluorescent and mercury lamps, with similar economic lives, provide several combinations which will answer particular needs in many manufacturing plants. With similar lamp lives, these two sources are a "natural" to effect group relamping and maintenance in industrial areas. Group relamping and maintenance have often been difficult in the mercury-filament combination, with the filament replacements running six to one over the mercury replacements. Labor charges alone are hard to justify. Consequently, many lighting systems are allowed to continue at half their original design level.

Fig. 8 of the paper shows an area quite familiar to the discusser. It should be emphasized that the half of the area not shown is lighted with a mercury-filament combination of the same geometry. Lack of maintenance, for the filament units not shown, rears its ugly head, and the situation worsens when the obvious comparison with the mercury-fluorescent system is made. Other shops in this plant (approximately 1,500,000 square feet) can easily be converted from the existing mercury-filament systems to mercury-fluorescent systems. Benefits to workers and production speak for themselves.

*Electrical Facilities Engineer, General Electric Co., Erie, Pa.

KURT FRANCK:* The paper points up well the inherent advantages of mercury industrial lighting and the suitability of auxiliary or stand-by fluorescent lighting because of the similarity of the two light sources as regards light output per watt, lamp life, and electrical operating characteristics. Several questions arise:

In view of the wide-spread acceptance of improved-color mercury lamps, the need for improving color by adding incandescent or fluorescent units to the installation no longer exists. Increased usage of constant wattage transformers has considerably reduced the likelihood of mercury lamp outage in service. For these reasons would it not be sufficient to consider the fluorescent auxiliary lighting strictly as a stand-by installation at minimum footcandle level, taking full advantage of the high utilization of the mercury system, as pointed out by the authors?

In Table I the efficiency comparison is made on the basis of lamp output. Would it not be of more practical value if the table were based on coefficients of utilization of complete luminaires using these various lamps, so as to compare directly illumination results on the work plane?

The authors mention the beneficial effect of an upward light component suggesting that it be obtained by the auxiliary fluorescent lights. Again, would it not be more practical to use mercury luminaires with upward light component?

Finally, are the cost comparisons of Figs. 3 and 4 based on the use of the newly introduced "bonus" mercury lamps of better lumen maintenance through lamp life or, if not, how would consideration of these bonus lamps affect the cost figures given in Figs. 3 and 4?

W. S. TILL:** This is an interesting and timely paper which will help promote better lighting. At first I was inclined to view any move to promote a marriage of fluorescent and mercury lamps with some degree of suspicion, but I think the authors' intentions are probably good.

It appears to me that the authors are quite worried about the effect of power interruptions in installations using only mercury lamps. I have never heard of an accident from such a cause, and one reason may be that a small percentage of stand-by emergency lighting, operating from a different circuit, is usually included in critical areas. This is good protection in any lighting system, regardless of the light source. In other installations, local machine lights are often used, and these help during a momentary outage. These lights can be fluorescent, if desired.

The authors speak of using fluorescent luminaires to improve upward lighting. Of course, the same thing can be done with an all-mercury system and is being done in many well-designed new lighting installations.

The choice of the H400 RW1 (also known as the P-H1/SW or H1-LK/W under the new ASA code) as the most economical light source for the comparison shown in the paper is surprising, as the area is 80 x 140 feet with the lighting equipment mounted at 44 feet. I would have expected 1000-watt mercury lamps to be considerably more economical, and I would like to ask the authors if they included the 1000-watt lamps in their cost comparisons.

I would also like to ask for an explanation of Figs. 2, 3 and 4 showing relative costs for lighting systems of mixed mercury and fluorescent or filament lumens. The statement is made with respect to Fig. 4 that: "the typical total annual cost for a mercury and filament system, using system B with *equal* lumens supplied by each lamp type, is approximately 1.7¢ per footcandle per hour for 10,000 square feet of lighting." The diagram shows lumens at the 1.7¢ point zero per cent mercury and *100 per cent* filament lumens. We would appreciate an explanation.

We note that there is no apparent difference in cost for a mercury system combined with high-output or combined with high-output fluorescent lamps of non-circular cross-section. This is indeed surprising in view of the difference in output ratings of these fluorescent types.

WARD HARRISON:* The data given in this paper are very impressive and certainly indicate that high power fluorescent lamps may be expected to replace incandescent as a companion of mercury sources in high-bay industrial plants. The authors are correct in saying that cost is a large factor in the choice of lighting equipment for such interiors. I would like to ask whether the improved candlepower life performance of mercury sources, recently announced, has been taken into account in these calculations. If not, how much would it improve the data given for RW1, the mercury lamp?

A considerable advantage of a fluorescent installation over mercury lies in softer shadows and reduced specular reflection from the fluorescent. In certain cases, this difference may, in my opinion, be sufficiently important to indicate the choice of fluorescent alone. A considerable part of difference in cost between mercury and fluorescent is represented by the initial investment and ways may be found to bring this down somewhat, as time goes on.

M. CHRISTENSEN AND Q. D. DOBRAS:** The authors wish to thank all of the discussers for their comments and interest shown in this paper. The number of comments indicates that the paper has served its purpose of stimulating interest in combination mercury and fluorescent systems.

Mr. Burroughs' comments are particularly appropriate, since he is responsible for, and has had experience with, a large installation of the type discussed in the paper.

In reply to Mr. Franck, we agree that there is less need for combination systems today, as pointed out in the opening paragraphs of the paper. However, "the need still exists for additional light sources which instantly restart when power is restored."

It would have been desirable to show comparisons of utilized lumens in Table I, but this would have limited the data to one particular set of conditions. All of the cost comparisons, however, are based on maintained light on the work surface.

Regarding the comments on upward light, we would certainly recommend the use of mercury luminaires with substantial amounts of upward light for all new installations. In our paper, we were referring to improvements in existing installations by the addition of fluorescent upward lighting units.

The "bonus line" of mercury lamps were not available when these cost studies were made. The use of these lamps would have the effect of reducing the over-all cost of a 100 per cent mercury system by about 10 per cent. On the other hand, recent improvements in high-output lamps of non-circular cross-section have reduced the cost of a 100 per cent fluorescent system by approximately 20 per cent. These

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improvements make the combination mercury and high-output of non-circular cross-section systems even more economical than before.

Several of Mr. Till's comments have been included in the above discussion. Our cost analyses show the H1LK/W (H400RW1) system to be about equal in over-all cost to the H15KY/W (H1000RW15) system. We used the 400-watt system due to its wider usage and improved comfort.

The cost figures shown in Figs. 2, 3 and 4 are relative values and not comparable to the actual cost figures of 1.7¢ per footcandle per hour for 10,000 square feet of lighting.

At the time the paper was written, our analyses showed the over-all costs of the high-output and high-output of non-circular cross section systems to be about equal. As previously stated, improvements in the high output of non-circular cross-section system have resulted in a 20 per cent reduction in the over-all costs shown.

We certainly agree with Mr. Harrison's comment that fluorescent systems result in softer shadows and reduced specular reflections. This added comfort plus improved economics with today's higher powered fluorescent sources is a significant factor in the increased usage of fluorescent lamps in combination with mercury, as well as 100 per cent fluorescent systems.

Modern Lighting for Ancient Animals

The visual task at the Smithsonian Natural History Building includes dinosaur skeletons, for which IES has, as yet, set no recommended levels of illumination. The hall is 50 feet wide by 165 feet long, with a diffusing glass skylight 65 feet above the floor. A total of 1134 extra-high-output 1.5-ampere lamps are mounted in semi-continuous rows 6½ feet above the skylight, providing 65 footcandles at floor level. Similar installations are used in the East, West and North halls.

The installation replaces the original daylighting skylight in the roof structure, which has been filled in with conventional roofing materials. Photo and data courtesy of Sylvania Lighting Products, Division of Sylvania Electric Products, Inc., Salem, Mass.

Figure 1. Aerial view of plant where tests were conducted. View shows open area of surrounding cotton fields.

Maintenance Factors and Features of

Industrial Fluorescent Luminaires

By GEORGE J. TAYLOR
R. D. BRADLEY

In-service performance of industrial fluorescent luminaires having varying degrees of up-light have been studied under controlled testing to provide factual data on the economics of industrial luminaire maintenance.

MAINTENANCE of lighting systems is a subject which, like death and taxes, seems to be with us always. Various theories, studies and proposals have been discussed many times in the past, from the floor and in print.

Behind all this discussion, however, has been the need for factual information on what actually happens in service. Such information has not been easy to get. Comprehensive maintenance studies become pretty involved when they try to simulate actual conditions found in factory production areas, and maintenance studies attempted in actual industrial areas present problems too. Working factories are usually unable to provide space for prolonged testing; such tests must be prolonged if the results are to be of any value. Establishing a test area which remains "constant" over a long period of test-time has been another real problem, yet reliable and realistic data depend on such condition.

Maintenance data which may be depended on are of particular importance to industry these days, all the more so with the current demand for higher levels of illumination. Poorly maintained lighting systems depreciate in light output — ergo, reduce production output.

Lack of available information in actual practice has led to many hazy estimates, if not guesses, in applying *maintenance factors* (MF) for luminaires in industrial areas. This is especially true of the new types of fluorescent luminaires currently used for factory lighting. The prime purpose of the in-

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 17-22, 1958, Toronto, Ont.
AUTHORS: Day-Brite Lighting, Inc., New York, N. Y. and St. Louis, Mo., respectively.

service study was to provide at least a start in securing maintenance data for present-day industrial lighting systems. While only one condition of an interior was tested — that of dust and dirt — the results show evidence of the necessity of actual in-service data in the proper application of maintenance factors for specific job-areas.

Although there are many varieties and combinations of reflector styles and fluorescent lamps used in production areas, in general they fall into three categories as described in the Taylor-Bradley paper "Visual Comfort and Cost Analysis for Production Lighting" (ILLUMINATING ENGINEERING, April 1956, p. 293). Broadly, the three classifications are:

(1) Solid top reflectors with all light directed downward.

(2) Slotted top reflectors with approximately 10 per cent uplight.

(3) Slotted top reflectors with approximately 30 per cent uplight.

Test Area

The authors were fortunate in being provided with an actual production area where maintenance studies could be conducted under the circumstances most conducive to obtaining factual information. The plant where tests were conducted is located in a suburban section on the edge of a small town. It stands in an open field with few neighboring manufacturing plants. In this respect, it can be said that the plant is situated in an area free from surrounding outside dust, dirt and smoke. See Fig. 1.

The test area is in a centrally located section of a large newly constructed manufacturing plant. It covers a space of 56 by 96 feet or over 5,000 square feet. The nature of the class of work being conducted in the test area is light manufacturing, consisting of the assembly and wiring of luminaires. The atmospheric conditions can be described as generally clean, by observation, with dry suspended dust particles floating in the air about the area (see Fig. 2).

The ceiling in the test area is composed of large panels of Fiberglas sprayed with a white paint. Steel upright columns are spaced on 24- by 56-foot centers and painted white. The floor is of medium light grayish concrete.

Test Equipment

Luminaires in the test area are arranged so that there are two continuous rows in each 24- by 56-foot bay (see Fig. 3). There are seven 8-foot luminaires per row or a total of fourteen for each test "group." Reflectors are porcelain enameled and equipped with two 96-inch standard cool white slimline, 430 ma lamps. The three types or classification of luminaires previously mentioned are more specifically described as follows:

1 — *Group I* — Solid top reflectors with all light directed downward. Luminaires designed for nominal 8-foot channel lengths with open bottom and open end reflectors.

2. *Group II* — Slotted top reflectors with 11 per cent uplight and the remaining light directed downward. Luminaires designed for nominal 8-foot channel lengths with open bottom and open end reflectors.

3. *Group III* — Slotted top reflectors with conditions as cited below. Luminaires designed for nominal 8-foot channel lengths with:

Figure 2. View showing interior of plant. Workers are shown in test area.

A — Louvered bottom reflectors providing 30 per cent uplight.

B — Open bottom and open end reflectors providing 27 per cent uplight.

The ceiling is 16 feet above the floor. Luminaires are mounted 14 feet above the floor (to bottom of reflectors). Consequently, the distance from the bottom of reflectors to the ceiling is two feet.

Test Conditions

Under each test "group" of luminaires are located nine test stations. These stations are identified by painted spots on the floor. The stations were positioned with three directly under each test row of luminaires and three mid-way between the two rows comprising each test "group" (see Fig. 3).

The predominant *working plane* was established at 40 inches above the floor since most of the visual tasks were performed at this level. A "jig stand" was made to hold the test meter at this distance above the floor to assure accuracy and for ease in handling.

Test readings were taken with a Weston Model 603 Illumination Meter ,Serial No. 1309 — visual and cosine corrected. The meter was laboratory checked before each series of readings to assure accurate measured results. Voltage at the panel board measured 240 volts at the beginning of tests. Periodic readings indicated that the voltage remained constant during times when light measurements were taken.

Test readings with the Weston Meter were recorded at each station with all test luminaires and all surrounding luminaires adjacent to the test area lighted.

Tests were started on April 21, 1955 and concluded on March 11, 1958.

All luminaires in the test area were newly installed and were not operated prior to the first set of test readings recorded. However, the units were operated at least 100 hours to season lamps before these recordings. Readings were taken on the following schedule of dates:

April 21, 1955	November 3, 1956
June 16, 1955	April 9, 1957
October 1, 1955	October 12, 1957
February 25, 1956	February 8, 1958
May 26, 1956	March 1, 1958
	March 11, 1958

The last authentic set of readings used in the tests were those of October 12, 1957. The February 8, 1958 tests were not used for reasons to be explained later. The March 1 tests were made with new seasoned lamps and thoroughly washed reflectors. On March 11 several brightness (reflectance) readings were taken.

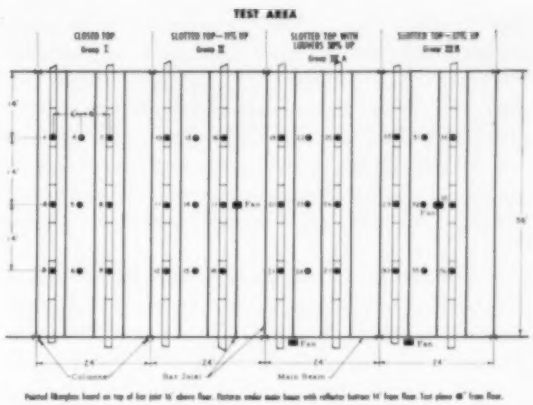


Figure 3. Plan view of test area showing essential equipment and dimensions.

When each set of test readings were recorded, all stacked raw materials and finished goods were removed from the test area. This prevented any possibility of light obstruction at station points. When lamps burned out in the test area they were replaced with lamps of equal life from adjacent areas. Care was exercised so as not to disturb dust and dirt that had accumulated on these lamps.

The lighting installation was operated on a two- and three-shift schedule at approximately 350 hours per month. Luminaires were switched on and off twice a day resulting in about 10 hours per start for lamps.

Lamp Performance Record in Test Area.

From April 21, 1955 to	Approximate Hours Operated	Lamps Replaced Number	Percentage
May 26, 1957	8320	2	3.5
October 12, 1957	9730	21	37.5
February 8, 1958	10140	27	48.3

All luminaires surrounding the test area were washed during the month of June 1957. Test luminaires were not washed at this time.

Variable Conditions

When tests were first started in April 1955, the building was fairly new. One large circulating fan had been operating in the "wiring" section of the test area and another nearby had been blowing in the direction of the entire test area. Also, additional fans were installed in the test area in April 1956 (see Fig. 3). Just prior to this, a hot and dry spell had hit the community. Two large parking areas nearby the test area had not been paved and much dust was suddenly aroused and driven into the building. This, together with the fans, circulated

more than the normal dust into the test area, causing an accelerated increase in depreciation between the test dates of February 25 and May 26, 1956. By August 1956 the parking lots were paved to prevent continuation of this abnormal dust condition and test results again resumed a normal rate of depreciation. Proper adjustments were made to account for this discrepancy and are included in the plotted results.

The occasion of the higher dust content for a short duration indicates the importance of more definite knowledge in assigning proper *maintenance factors*. It is not enough to assume a room condition of dust and dirt and then merely estimate the rate of depreciation in relation to a cleaning schedule which might permit lower than desirable minimum lighting levels.

When readings were taken on February 8, 1958 the results showed a slight increase in light output from previous readings. The reason for this was the fact that a few months before this all the luminaires in the plant had been washed, with the exception of those in the test area. By this time, lamps in the test area had been failing rapidly reaching about 50 per cent by February 1958. Replacement lamps in the test area were taken from the adjacent washed area. Obviously, such washed lamps delivered more light than the old unwashed lamps. This is merely a point of interest in cautioning experimentors of the care that must be taken when long testing periods are necessary.

Test Data

As previously explained, there are nine test stations located under each *Group* of luminaires. The nine readings were averaged for use in data presented in this paper and in the preparation of graphs. The significant data accumulated over approximately 2½ years are plotted in graph form in Fig. 4. The upper set of curves are plotted directly from the average readings mentioned above. The lamp depreciation curve is taken from recent information provided by lamp manufacturers.

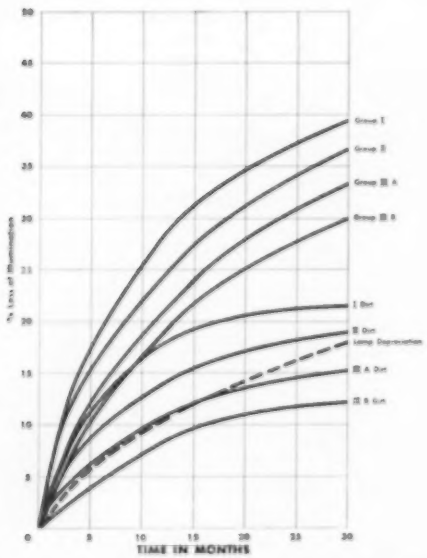


Figure 4. Depreciation curves as plotted from test data.

The upper set of curves in Fig. 4 represents the rate of depreciation of dust and dirt accumulation on lamps and reflectors and the normal depreciation of the lamps. The lower set of curves show the rate of depreciation due only to the dust and dirt accumulation on lamps and reflectors.

In the case of luminaires having slotted top reflectors, a certain percentage of light loss will result in reflected light due to ceiling depreciation. While this paper does not attempt to show depreciation losses due to ceiling and surrounding reflectances, the following information is of interest:

Surround Surface Depreciation in Test Area.

	Average Reflectances at start	at end	Per Cent Decrease
Ceiling	.84	.68	19
Columns	.87	.72	17
Floor	.34	.22	35
Work (material)	.42	.49	—

Reflectance readings were taken with Spectra Brightness Spot Meter No. 125. Several readings were taken on work surfaces and stored materials in the test area with averages as noted.

Test Analysis

The results plotted in Fig. 4 disclose information of value in the study of maintenance of industrial luminaires. To cite one specific example, the dust and dirt accumulation is tabulated below, using Group I (solid top reflectors) as units with maximum rate of depreciation in comparison with other types of units tested after approximately 30 months' service.

Relative Depreciation Due to Dust and Dirt.

	In Per Cent of Group I
Group I (Solid Top Reflector)	100
Group II (11% Uplight)	87.5
Group III	
A (Louvered — 30% Uplight)	71.5
B (27% Uplight)	56.0

There is another factor that generally contributes to the loss or depreciation of light, referred to as lamp mortality. In large lighting installations it is not always convenient or economical to spot-replace lamps as they burn out. However, it would be to the detriment of working conditions to allow burn-

outs to exceed but a few per cent of the total lamps in service. A third factor accounting for loss of light is lamp depreciation, which like dust and dirt is common to all types of industrial luminaires.

The curves in Fig. 5 show, in combination, the three normal, major contributing factors in depreciation or loss of light output:

(1) Loss due to lamp depreciation and mortality,
(2) Loss due to lamp mortality only,
(3) Total loss including dust and dirt.

The lamp mortality curve, as drawn, is adjusted to actual operating performance as experienced during the test period. This is, therefore, based on an average lamp life of 11,000 hours. The "variable" depreciation curves due to dust and dirt accumulation (Fig. 4) when added to the plotted results of the lamp depreciation and mortality curve produce the four "total depreciation" or loss of light curves in Fig. 5.

It is obvious that if no maintenance attention is given to a lighting installation a depreciation in excess of 50 per cent is possible. Yet, it is inconceivable that lamps would not be replaced shortly after they burn out unless a strict group relamping schedule is followed, where a few per cent of lamp outages are allowed prior to complete relamping. If lamps are replaced as they burn out, the depreciation due to mortality can be overlooked. Perhaps it should be explained that with an installation of new lamps it can be expected that about 50 per cent of the lamps will burn out at 100 per cent of rated life. In the tests reported here only a few lamps burned out between 10 to 15 months and about half of them burned out after slightly more than 30 months.

When new lamps replace burned out lamps, the rate of burnout of these lamps will be similar to the mortality curve shown in Fig. 5. If the curves of these renewed lamps were added, at the proper intervals, after the time when lamps are renewed, to the burnout curve of the original installation, a composite curve would result. After the second to third *rated life period* the replacement of lamps would level off to the extent where approximately the same number of lamps would be replaced monthly. In the installation tested this period would not be reached until after the sixth or seventh year.

Obviously, when burned-out lamps are replaced there is no loss of light due to mortality. When the leveling off period is reached, there will not only be no loss of light due to lamp mortality but with new lamps mixed with old lamps, the lamp depreciation will be maintained at some higher average rate than for old lamps only.

The merits of individual or spot replacement

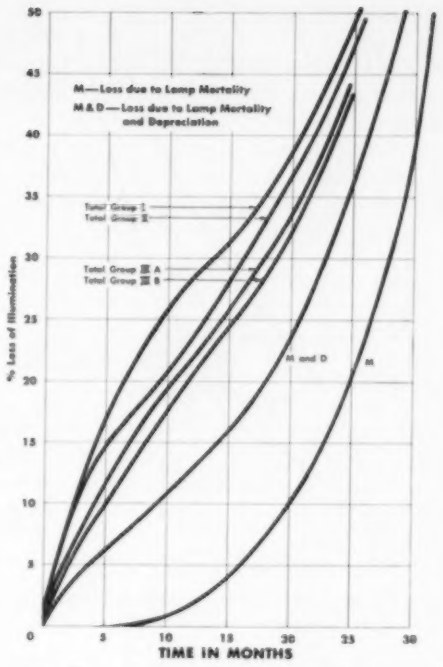


Figure 5. Total loss of light due to dust and dirt accumulation, lamp depreciation and lamp mortality.

compared to group relamping have been discussed by many at some length. The authors favor the group relamping maintenance schedule since it is the most economical procedure to follow when considering the importance of cost of light delivered at the point of seeing.

The I.E.S. Committee on Recommendations for Quality and Quantity of Illumination has recommended that levels of illumination be established for specific seeing tasks and that these levels be considered as a "minimum on the task at any time." Therefore, the maintenance factor no longer is to be considered in providing average footcandles for seeing tasks. Instead, it must provide for a value that will not go below the level of illumination prescribed at any time for the seeing task. This means that when the amount of light (footcandles) falls to a predetermined level, something must be done. The assignment of a maintenance factor (MF) must be carefully considered. Moreover, the atmospheric conditions of a room will have a direct bearing on the MF selected. So it is that the accumulation of dust and dirt becomes the truly variable factor in maintenance.

One approach in determining the MF for a lighting system such as reported in this paper would be to construct a set of curves as shown in Fig. 6. The example relates to Group II type luminaires (10 per cent uplight). Assume that MF = .75. Then

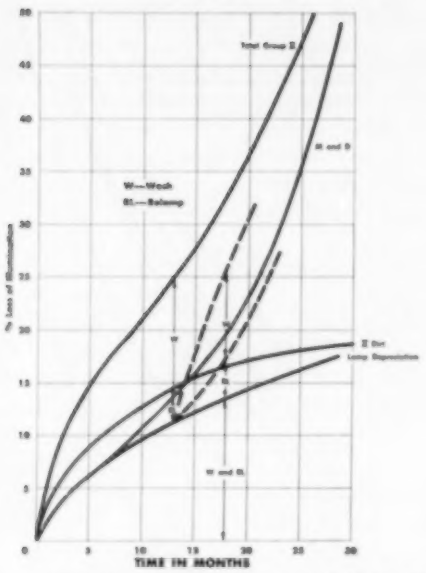


Figure 6. Analysis of maintenance schedule for Group II luminaires assuming MF = .75.

when the total *depreciation curve* crosses the line at 25 per cent loss in illumination, something must be done. If the luminaires are washed at this time (13 months) 11.5 per cent of the light is regained. Another 2.5 per cent is realized by replacing burned out lamps, making a total of 14 per cent. This establishes the *lamp depreciation* curve as a new base point at 13 months. From this point are drawn new *total depreciation* and *lamp mortality and dust and dirt curves* (dotted lines). The *total depreciation* curve crosses the 25 per cent loss in illumination line at about 18 months. Washing luminaires picks up about 8 per cent and relamping of burned out lamps about 4 per cent.

To repeat the above related procedure again would prove impractical and uneconomical. This is due to the fact that at 18 months lamp depreciation has reached a value of about 13.5 per cent. Also, the original lamps are beginning to burn out at a rapid rate. So little would be gained in increasing light output for the time and money spent when the 75 per cent line is reached the third time. Consequently, it is recommended that luminaires be washed and all lamps replaced at the 18th month. When this is done, the original illumination level is restored and the cycle of events is repeated.

Maintenance Factors

Perhaps a more practical and simple approach would be to assign maintenance factors for each room condition. For instance, the test results shown in Fig. 4 may be considered as taken in a room with fairly clean conditions. The next thing would be to determine the hours the lighting system will be operated per year from which a mortality curve can be drawn, as in Fig. 5. Now consider group relamping as the most economical maintenance program to follow. In this connection there are two methods that have been used:

System 1 — Group relamp when 10 per cent of lamps burn out,

System 2 — Same as above but also spot relamp the 10 per cent burnouts.

From the above analysis, maintenance factors can be assigned for various types of luminaires for specific room conditions. Taking the conditions from the tests conducted, with 10 per cent of the lamps burned out at 20 months:

Assigned Maintenance Factors at Twenty Months.

Luminaire Group	System 1 from Fig. 5	System 2 from Fig. 4
I	.61	.66
II	.64	.69
III A	.67	.72
III B	.69	.75

The above maintenance factors would be used in computing for illumination levels using the lumen method. If lamps are permitted to burn out without spot replacement of these lamps, the light output suffers approximately in proportion to the burnouts. To compensate for this, the MF would be as shown in the above tabulation for the maintenance program of System 1. This would require about 10 per cent more luminaires to achieve the minimum footcandles required for a given visual task, so it appears wise to follow System 2 using the figures shown for MF. This would mean that at the end of 20 months each of the "groups" of luminaires would have depreciated to a predetermined value of say, 100 footcandles, at which time it is recommended that all lamps be replaced and luminaires washed. Some proponents of group relamping programs suggest that the spot replacement lamps be marked and used again for replacement purposes after the first group relamping. Other suggestions have been proposed but it is not within the scope of this paper to discuss their merits.

Economics

The establishment of MF becomes an economic factor depending upon conditions within a given room or shop area. In the particular area where tests were conducted, the essential factors of general interest are tabulated in Table I. The assignment of MF takes into account that at the end of 20 months 100 footcandles will be obtained after which group relamping will take place and luminaires

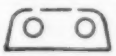
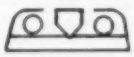
washed to restore the original level of illumination.

The results shown in Table I in regard to costs do not presume the necessity of washing luminaires except at the end of the 20 months' operation. Another approach would be to assign some value such as MF = .75 to all "groups" of luminaires as previously discussed. If this were done, a planned maintenance schedule would have to be determined for each lighting system depending upon the type of luminaires used.

Obviously, when MF values increase, the number of luminaires required for the job decreases. On the other hand, if high MF values are assigned without care, then it is quite possible that more frequent washing schedules will be necessary.

The matter of economic balance is not an easy

TABLE I — Comparison of Industrial Lighting Systems.

Room Size: 100′ x 100′ Mounting Height: 14′ Room Index: A Room Finish: 75/50/15 Lamps: Cool White Slimline	Luminaires equipped with all-white all-porcelain reflectors.		Watts: 174 per luminaire Power: 1 ½ ¢/KWH Average Annual Costs Based on 100 Footcandles Minimum.	
	 GROUP I Solid Top	 **GROUP II** 11% Uplight	 **GROUP IIIA** 30% Uplight Louvered	 **GROUP IIIB** 27% Uplight
Maintenance Factor (MF)	.66	.69	.72	.75
Coefficient of Utilization	.72	.74	.64	.71
Footcandles (Initial)	152	145	139	133
Number of Luminaires	210	196	217	188
Total Number Lamps	420	392	434	376
Number Lamps Replaced (10% at 20 months)	42	39	43	38
Aver. Annual Cost Lamps (Group relamp at 20 mos.)	$ 640.00	$ 597.00	$ 662.00	$ 573.00
Aver. Ann. Group Relamp. (Labor at 10¢/lamp)	$ 25.20	$ 23.50	$ 26.00	$ 22.55
Aver. Ann. Spot Relamp. (Labor at 50¢/lamp)	$ 12.60	$ 11.70	$ 12.90	$ 11.40
Tot. Aver. Ann. Relamp Cost (Group and Spot Replacement)	$ 37.80	$ 35.20	$ 38.90	$ 33.95
Tot. Aver. Lamp Cost (Lamps and Labor)	$ 677.80	$ 632.20	$ 700.90	$ 606.95
Cleaning Cost/Luminaire	$ .60	$ .60	$ 1.00	$ 0.80
Annual Amortization (10% of Original Cost)	$1140.00	$1060.00	$1465.00	$1080.00
Annual Power Cost (1½¢/KWH)	$2190.00	$2050.00	$2270.00	$1960.00
Tot. Aver. Ann. Oper. Cost	$4083.00	$3813.00	$4566.00	$3737.00
% of Group I	100	93	112	91
Total First Cost (Includes Lamps)	$12,400.00	$11,600.00	$15,700.00	$11,700.00
% of Group I	100	94	127	95
Glare Factor—Crosswise	(G) 230	(G) 190	(C) 27	(C) 30
Glare Factor—Lengthwise	(G) 200	(G) 160	(C) 33	(E) 80

one to determine in a work world of many variables. Several other factors beside atmospheric conditions confront the industrial management in scheduling maintenance programs. To mention a few: Work interruptions, Interior appearance, Employee morale, Management pride, Plant efficiency, and Production problems.

It is interesting to note that the manager of the plant where the tests were conducted, without prompting, had all luminaires (except in the test area) washed at about the 25th month of operation. The time selected was during a two-week vacation shut-down period. The reasons for the decision to wash included among others those mentioned above and the desire to increase the illumination level.

The authors wish to strongly emphasize and stress the fact that the tests here reported are not to be construed as an answer to all lighting maintenance problems; far from it, as repeatedly mentioned. The tests are for one set of conditions only and afford valuable information in this direction. Continued tests of a similar nature are required with different room conditions. Previous experimenters have made data available that can be used in conjunction with the data presented in this paper. For instance, tests conducted by others in the past on fluorescent luminaires with closed top reflectors might well be used in determining results with slotted top reflectors by means of mathematical proportions from data given in this paper.

The authors also want to again plead for greater consideration for the seeing comfort of the workers in applying luminaires in industry. Some strides have been made in this direction but there remains much to be desired.

With present day demands for a maintained minimum level of illumination as recommended by the R. Q. Q. Committee, the results shown in Table I were calculated to show that economy and comfort may be achieved to a great extent. For about the same *first cost* and *annual operating cost* (Group II *vs.* Group IIIB) of a lighting installation, a very substantial improvement in comfort is obtained as noted by the glare factor ratings. The Group IIIB luminaires are generally suitable for comfort of seeing where workers are confronted with critical seeing tasks and are not seated in one position for long periods of time. Where concentration is required for long periods on difficult seeing tasks, the Group IIIA luminaires are quite necessary if visual comfort is expected. Perhaps economy of installed costs may not always be realized, but the results in improved efficiency and production as well as happy workers will very often far offset this original investment.

Acknowledgments

The authors gratefully appreciate the cooperation of Chauncey Godwin, Manager of the Tupelo plant, for granting space and controlled conditions in the test area. Sincere thanks go to Leonard Beckering of Tupelo for his careful vigilance during the extended period of testing time and in recording "laboratory" accurate test data.

DISCUSSION

D. R. PHILLIPS AND M. CHRISTENSEN:* The authors could not have picked a subject which is more urgently in need of study than lighting maintenance.

The comparisons of closed top, 11 per cent and 27 per cent uplight types of luminaires are particularly interesting. The bottom set of curves in Fig. 4 indicates the rate of depreciation due to dust and dirt accumulation on "lamps and reflectors." From the paper, we would assume that the depreciation of ceiling reflectance is also included in these curves. This depreciation is substantial, as shown in the table on reflectances. Therefore, the maintenance characteristics of the 27 per cent upward light luminaire are even better than indicated by the authors.

It was also interesting to note that a louvered 30 per cent upward light unit had a better maintenance factor (ceiling depreciation included) than either the closed top or the 11 per cent uplight unit.

The authors pointed out that at the beginning of the tests abnormal conditions were present that required adjustments in the data. It would be of interest to know just how these adjustments were made, since the maximum rate of depreciation occurs during the first few months after the lighting system is installed.

The VandenBoom-Egeler[1] paper presented data on closed top fluorescent units in various industrial areas. We compared the data for the woodworking shop in the VandenBoom-Egeler paper to the Taylor-Bradley data for closed top units (see Fig. A). It can be seen that the best correlation of data occurs when the VandenBoom-Egeler data are plotted against burning hours rather than against the age of the installation. This would seem to verify the assumption that depreciation occurs more rapidly when the lighting system is on than when it is off. Future researches are

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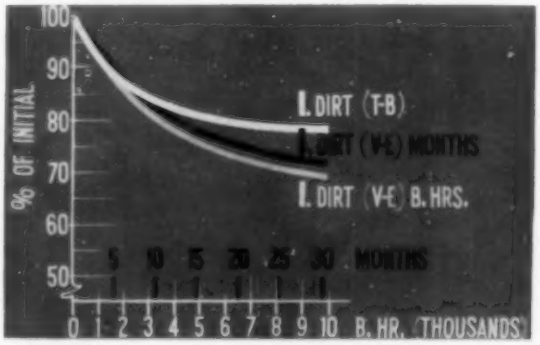

Figure A. Correlation of Taylor-Bradley and VandenBoom-Egeler data.

needed to supply the answers to this and other aspects of lighting maintenance. Let us hope that these investigations will be made soon to supplement the useful data which Messrs. Taylor and Bradley have presented.

1. Egeler, C. E., and VandenBoom, R. F.: "Maintenance of Industrial Lighting — Part II," ILLUMINATING ENGINEERING, Vol. XLVIII, No. 12 (December 1953).

WILLARD ALLPHIN:* This valuable paper seems to supply just the sort of factual data which the Lighting Maintenance Committee is seeking. In fact, a form which the Committee has prepared will make it easier for others to collect such data.

I have one bit of carping criticism: I would have much preferred to see the depreciation curves plotted either in footcandles or in per cent of initial illumination. Did the authors have a good reason for plotting them in per cent loss of illumination?

C. W. MCCORMICK:** I commend Messrs. Taylor and Bradley on this fine contribution to industrial lighting.

I would like to make several comments concerning maintenance factors for industrial lighting. I believe the authors were negligent in ignoring the reflective depreciation of the ceiling in the test area, since they were comparing direct and semi-direct luminaires. The ceiling reflection factor would surely have a bearing on the MF selected for the latter system.

Another thing indicated by the paper is the possibility of leaving outage in place until a prescribed time of replacement. One must remember, however, that if series ballasts are in service, the outages may destroy the ballast, depending on which lamp in a two-lamp luminaire fails first. This point is made in the interest of economy.

Finally, of no criticism of the paper, frequent field tests of luminaires in service show a certain lack of standardization in ballasts, so that no matter which MF is selected, the illumination initially and throughout the lamp life may vary up to ± 15 per cent, with voltage remaining constant.

R. L. ZAHOUR:† I wish to congratulate the authors on the arduous task they have undertaken in an effort to show that standard maintenance factors, which we have been using to calculate general interior lighting for the past 30 years, are not sufficiently accurate when applied to current industrial luminaire designs.

During the current decade, manufacturers of industrial fluorescent and mercury high bay luminaires have introduced the added feature of slots in the top of reflectors to provide an upward component that illuminates white ceilings and thereby creates a comfortable visual brightness contrast between the luminaire and its background. Besides, this slotted arrangement provides a certain degree of ventilation. Air currents which pass upward through the slots not only ventilate but also carry away many of the dust particles which ordinarily would become trapped in a non-ventilated direct-type reflector, and settle on the lamps and reflector surfaces.

Results of studies comparing the rate of depreciation due to dust accumulations on ventilated and non-ventilated reflector surfaces have been reported by Steiner[1] for high bay mercury luminaires and by Sell[2] for fluorescent luminaires. Each author reveals the economic savings with ventilated luminaires because in a given length of time, fewer cleaning periods are required to revive their initial efficiency. Thus, in many instances, group relamping may be coordinated with cleaning periods at even greater saving in labor cost.

From the plotted curves in the paper, it appears that a system of better maintenance factors could be developed for ventilated luminaires, just as the Zonal Method of calculating coefficients of utilization has given us more accurate design data. I believe that some relationship may be found between the per cent upward component and ultimate maintenance factor of a given range of luminaire designs, which may lead to a simple formula for determining MF's.

The IES Dirtometer, developed by the IES Lighting Maintenance Committee, can be of help in further dust and direct collection studies on lighting equipment. This dirt depreciation data combined with the mean lumen output of the lamp may give us a more accurate maintenance factor for lighting calculations.

1. Steiner, J. W.: "Practical Reduction of Dirt Accumulation in High Wattage Luminaires," ILLUMINATING ENGINEERING, Vol. XLVIII, No. 4, p. 184 (April 1953).
2. Sell, Floyd W.: "Ventilation — The Key to Self-Maintenance," ILLUMINATING ENGINEERING, Vol. XLVIII, No. 9, p. 500 (September 1953).

G. J. TAYLOR AND R. D. BRADLEY:* The authors wish to thank Messrs. Phillips and Christensen for their constructive comments and will endeavor to answer the questions raised. The published curves were based on actual footcandle readings which did take into account any depreciation of ceiling or surround. If this lowering of reflection factors could be isolated or held constant at the original value, the per cent change in illumination chargeable to the dirt on lamps and reflectors would be somewhat different. The adjustment in data due to abnormal dirt conditions was corrected by plotting all data on curve form and raising the curve back to position to eliminate the abrupt drop which occurred at one point. It was found that all subsequent data paralleled this curve and as there was only one set of readings which would not fit these data within reasonable limits, this correction seemed reasonable and proper. The authors agree that burning hours might be a more accurate criteria than age of installation. Further study with recording equipment to record burning time could add to the data and give the key to the difference between "burning" and "cold" dirt collection. We feel that most plant servicing is done on an age, rather than a burning time, basis.

In reply to Mr. Allphin, the original plot of footcandles would not serve for the comparisons the authors wished to make, as the footcandle levels were different for the four bays. It was necessary to get a common base and as we were directly interested in per cent loss of illumination, this seemed the natural ordinate to use.

We believe the above comments on Messrs. Phillips and Christensen's discussion may have already answered Mr. McCormick's point on ceiling reflectivity. We are not aware that series ballasts are destroyed when one lamp is left in the failed condition. Most ballasts of proper design take this possibility into consideration and have sufficient latitude to prevent serious overheating under these conditions. We assume that Mr. McCormick was referring to ballasts built to output standards which may or may not be recognized by all ballast manufacturers. It is an unhappy fact that light output (or wattage) may vary over a considerable range for ballasts recommended for the same lamps.

We wish to thank Mr. Zahour for his discussion and since we are in agreement with him, no further comments seem to be necessary.

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A Discomfort Glare Evaluator

By S. K. GUTH
J. F. McNELIS

One important part of the over-all problem of obtaining quality of lighting is the development of a simple and practical method for evaluating the visual discomfort produced by luminaires and other sources of brightness. However, it has long been recognized that generalized conclusions derived from laboratory experiments must be substantiated by, or modified in accordance with, the results of investigations conducted with practical situations. Therefore, it is necessary to devise instruments and techniques which can be used to study typical lighting systems in such a way that the findings can be related to the fundamental data.

An extensive series of investigations[1] has provided considerable information about the relationships among the factors which influence discomfort in lighting. Adapting the technique used in these basic studies, a Discomfort Glare Evaluator has been designed and constructed. The purpose of this paper is to describe the evaluator and to present data obtained by a group of 50 observers for several combinations of luminaires.

Discomfort Glare Evaluator

General Technique. In order to be able to directly compare the results of so-called practical investigations with fundamental data, it is necessary to use a technique similar to that used in the laboratory. In the initial investigations[1] of brightnesses in the visual field at the borderline between comfort and discomfort (BCD), the technique involved momentary exposure of sources of brightness. The same procedure was used in subsequent experiments.[2,3] All of these included a number of conditions in which the brightness of a comparison source located on the line of sight was adjusted until it produced the same visual sensations produced by the brightnesses of sources above the line of sight. This technique permits rating a complex combination of sources in terms of the simple circular source used in laboratory investigations and about which a great deal is known. In this respect, the technique is similar to that used for evaluating the visibility of objects in terms of a standardized laboratory test object.

It is desirable to be able to "calibrate" observers in order to determine their sensitivity to brightness and how they compare with those who participated in the basic investigations. The same momentary exposure technique is used for this purpose. That is, the observer is required to adjust the test source until it produces a sensation at the borderline between comfort and discomfort. This is termed the BCD sensation. Thus, all data are obtained by the same method and are directly comparable. Since this has been found to give consistent and reliable results, it was adopted as the basis for the Discomfort Glare Evaluator.

Instrumentation. The components of the Discomfor Glare Evaluator, illustrated in Fig. 1, include a head-rest with movable and fixed shields, a light source, and control units for the experimenter and observer. A close-up of the head-rest with the movable shield in the "down" position and the observer's control are shown in Fig. 2.

Figure 1. Discomfort Glare Evaluator showing the head-rest with fixed and movable shield, test-source and control units.

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Figure 2. Close-up of head-rest showing movable shield in "down" position.

When the movable shield is in the "down" position, all of the test luminaires are excluded from the visual field of the observer. The chin-rest is adjusted so that the cut-off is just below the farthest luminaires. When the movable shield is rotated upward, all of the luminaires within approximately 50 degrees of the line of sight are included in the field of view. The movable shield is made of diffusing plastic, so selected, that when illuminated by nearby luminaires ,its brightness approximates that of the field. The fixed horizontal shield above the observer's head was added to shade the movable plastic shield from the luminaire directly overhead and to reduce disturbing reflections from equipment.

The circular test-source consists of a transilluminated diffusing glass. By using an appropriate filter between the lamp and the diffusing glass, apparent constancy of color of the test-source is obtained for relatively large changes in voltage. Lamps of appropriate wattage are selected to cover the desired range of brightness. This minimizes the possibility of the color of the source influencing the judgment of observers.

The circular test-source is viewed in a small diagonally positioned mirror (Figs. 1 and 3). This offers minimum obstruction of the far wall of the room. When the test-source is off, a "stand-by" brightness is provided which matches the far wall brightness. Furthermore, an appropriate gray mask, the reflectance of which is selected so its brightness also matches that of the wall, surrounds the test-source. Thus, the observer sees a luminous spot viewed against the far wall of the room. Throughout the entire investigation, the test-source was located on the line of sight at an apparent distance of ten feet from the eyes of the observer. Its diameter was 2.70 inches which, at the standard viewing distance, is 0.0004 steradian. This solid angle is within the range of sizes included in the original BCD experiments.

A timing mechanism in the operator's control unit governs the exposure sequence of the test-source and luminaires. When BCD evaluations are made, the movable shield on the head-rest remains in the "down" position at all times. The test-source is presented for one-second exposures separated by one-second intervals during which the observers are exposed only to the field brightness. A 10-second cycle is used during which the test-source is presented for a subjective evaluation three times, and the remaining short period is allowed for the observer to alter its brightness.

When making comparative evaluations of the lighting systems, the source on the line of sight — now termed the comparison-source — and the luminaires are alternately exposed to view. That is, the movable shield rotates upward so that the luminaires are exposed to view. During this period the comparison source is turned off. When the shield returns to its "down" position, the comparison-source is again turned on. The exposures are of one-second duration and they are separated by one-second intervals. Each group of three exposures is followed by a five-second period for evaluating the sensations and altering the comparison brightness of the comparison-source. The observers are required to adjust the brightness of the comparison-

Figure 3. General view of Condition D illustrating position of comparison-source on line of sight.

source until it produces the same visual sensation as the luminaires. At all times, the observers keep their eyes fixated upon the position of the comparison-source. They are permitted as many cycles as necessary for making an appraisal.

Experimental Conditions

Lighting. Five combinations of luminaires were selected for study in this investigation. They correspond to typical four-lamp 40-watt fluorescent units and were arranged as shown in Fig. 4. Condition D is illustrated in Fig. 3. The units were mounted five feet above the eyes of the observers who viewed the room lengthwise from the points marked "X" (Fig. 4). The spacing between rows was six feet, center-to-center, and the longitudinal spacing was on a four-foot module. Arrangements A and B, of course, are not typical lighting systems. They were included because it was desired to obtain as wide a variety of conditions as possible, but still consistent with the scope of the investigation. With the number of luminaires ranging from the minimum to maximum available, the wall brightnesses were from 1.3 to 34 footlamberts.

Observers. Fifty observers, selected at random, participated in the investigation. In general, they were considered naive, since only a few had ever participated in experiments of this sort, and then only in a preliminary exploratory study. Each observer made two sets of observations with each experimental condition: (1) BCD evaluations and (2) comparative evaluations of the luminaire combinations. The observers were permitted as many 10-second cycles as necessary for making a complete appraisal for each condition. A repeat series of observations was made by each observer on a later date, and the averages of both are used in the comparison and analyses which follow.

TABLE I — Observed BCD Brightnesses and Computed Values of Index of Sensation M for the Five Experimental Conditions.

Conditions	BCD Brightness (fL)	Field Brightness (fL)	Index of Sensation M
A	555	1.3	128
B	1237	6.8	130
C	1264	7.1	131
D	2118	20.6	133
E	2581	34.2	128

BCD Evaluations

The BCD evaluations provide a ready comparison with the original experimental data on circular sources.[1] When these observations were made, the movable shield remained in the "down" position at all times and the observers adjusted the brightness of the test-source until they judged it to produce a sensation at the borderline between comfort and discomfort or the BCD sensation. The mean values obtained by the 50 observers for each of the experimental conditions are presented in Table I and are plotted in Fig. 5. These brightnesses plot as a straight line on logarithmic coordinates and may be represented by the equation

$$B = 499\,F^{0.47} \qquad (1)$$

where B is the BCD brightness of the source and F is the brightness of the wall area against which the source is viewed. The latter is assumed to be the field brightness.

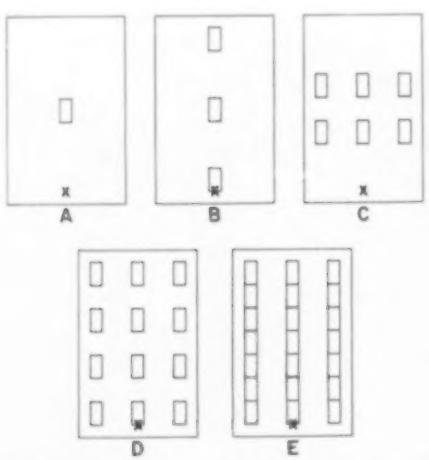

Figure 4. Arrangements of typical 4-lamp, 40-watt fluorescent luminaires used in the present investigation. Observer was located at position marked "X."

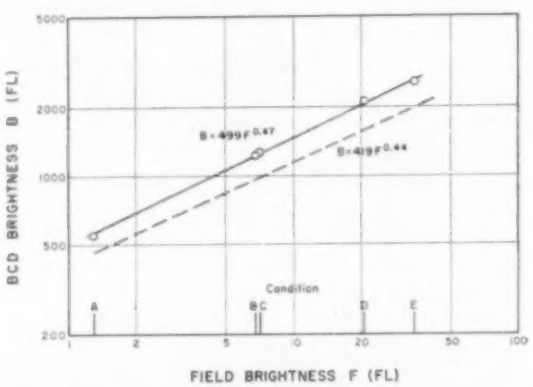

Figure 5. Relationship between BCD brightness B of test-source located on line of sight and field (wall) brightness F. Solid line represents results obtained in the present investigation and can be compared with those which were obtained in the original investigation (broken line).

The straight line relationship agrees with that obtained in the previous investigation. The broken line represents the relationship between B and F found in the basic BCD experiments.[1] The close agreement in the exponent of F is of particular significance. It indicates that the effect of increasing field brightness is judged by the present group of observers to be very nearly the same as that by the previous observers when the experimental procedure is identical.

The coefficient of F, as determined in this investigation, is approximately 20 per cent higher. This indicates that, on the average, the present group of observers is slightly less sensitive to brightness than the original group of observers. Another manner of illustrating the differences between the two groups is in terms of the index of sensation M. This has been computed for each condition by means of the basic BCD equation:

$$M = \frac{B}{P F^{0.44} (\omega^{-0.21} - 1.28)} \qquad (2)$$

where

B = BCD brightness in footlamberts,
P = Position index,
F = Field brightness in footlamberts,
ω = Solid angle subtended by the source in steradians.

The values of M (Table I) average 130 compared with 108 obtained in the original investigation. Such variations are not considered unusual because of the many physiological and psychological factors which influence subjective evaluations. They do emphasize the need for using large groups of observers in order to establish absolute brightness limits.

It was found that the subjective variations of relative BCD brightnesses were very similar for the five experimental conditions. Therefore, all the data have been combined and plotted on a normal probability integral scale as shown in Fig. 6. The relationship may be represented by a straight line which indicates a normal or Gaussian distribution. There appears to be a trend toward a slight flattening of the lower end of the relationship shown in Fig. 6. This would indicate that there probably is a lower practical limit of source brightness which no one would consider uncomfortable. That is, even the more sensitive observers would not be expected to object to a source brightness of about 20 or 30 per cent of the average BCD brightness.

The range of relative BCD brightnesses selected by the present group of observers was from about 20 to 205 per cent of the average BCD value. In the previous investigation,[1] that group of 50 observers indicated a range from 35 to 180 per cent

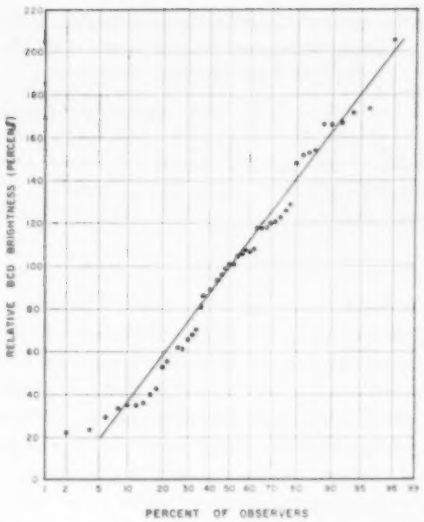

Figure 6. Per cent of observers who have judged specific relative test-source brightness to be at or less than BCD.

of average BCD brightness. In other words, the present group includes observers who exhibit greater and lesser sensitivity to brightness than the original group. While the average BCD is slightly higher, it is believed that the range is equally important.

These data indicate that the momentary exposure technique produces consistent results for the BCD sensation. Data obtained in this investigation compares very favorably with those obtained in the original BCD experiments and can be related to them.

Evaluating Luminaires

The primary purpose of the Discomfort Glare Evaluator is to provide a technique, comparable to that used in the laboratory, which will make it possible to determine how well an empirical method of computing discomfort glare ratings agrees with subjective evaluations.

In previous experiments,[4] limited data obtained with several typical lighting systems resulted in the development of a tentative proposal for rating groups of sources. However, certain limitations restricted the general applicability of this method to many practical situations. More recently a new method has been suggested by Fry[5] which appears to overcome many of the objections which have been raised regarding previously proposed methods. It is this new method which is being compared with the results of the present investigation.

In this part of the present investigation, the five combinations of luminaires shown in Fig. 4 were

TABLE II — Comparison-Source Brightnesses and Computed Ratings for the Luminaires of the Five Experimental Conditions.

	Experimental Conditions				
	A	B	C	D	E
1. Comparison Brightness (fL)	614	710	1476	1956	2567
2. BCD Brightness (fL)	555	1237	1264	2118	2581
3. Comparison/BCD	1.11	0.57	1.17	0.92	0.99
4. Luminaire Rating ($\omega/\bar{\omega}$)	0.73	0.25	0.92	0.60	0.74

evaluated by the 50 observers. The comparison method was used. That is, each observer adjusted the brightness of the source on the line of vision (comparison source) until it produced the same visual sensation as the luminaires. At all times, the eyes of the observers remained fixed on the position of the comparison source and the luminaires were seen by indirect vision.

The mean brightnesses of the comparison source of each of the experimental conditions obtained by the 50 observers are presented in line 1 of Table II. These values represent the subjective evaluations of five lighting systems which differ in the number and location of luminaires and in brightness distribution in the visual field. The relationship of each of these values to the corresponding BCD brightness (line 2) is an indication of the relative discomfort produced by the group of luminaires. These ratios are tabulated in line 3. If the comparison-source brightness producing the same sensation as the luminaires is equal to the BCD brightness, it is concluded that the lighting system is at the borderline between comfort and discomfort. The ratios of comparison/BCD range from 0.57 for condition B to 1.17 for condition C. These ratios correspond to relative BCD brightnesses. Thus, for example, using the relationship shown in Fig. 6, condition B is indicated as being acceptable to about 80 per cent of the observers. Similarly, condition C would be acceptable to less than 40 per cent of the group.

An interesting and significant comparison is in terms of the physical characteristics of the luminaires and the method of dealing with lighting systems suggested by Fry.[5] In brief, he proposed that a source of brightness be rated by

$$G = \frac{\omega}{\bar{\omega}} \qquad (3)$$

in which G is a glare or discomfort rating, ω is the solid angle subtended by the source and $\bar{\omega}$ is the solid angle required for the same source, acting alone, to produce a sensation at the borderline between comfort and discomfort (BCD). When computing $\bar{\omega}$, the source brightness, its position factor and the field brightness are the same as that for the source being evaluated. Equation (2) is used for determining $\bar{\omega}$ by using a value for M which corresponds to average BCD.

When a group of sources or luminaires is involved, the rating of the entire system is taken as

$$G_T = \frac{\omega_1}{\bar{\omega}_1} + \frac{\omega_2}{\bar{\omega}_2} + \frac{\omega_n}{\bar{\omega}_n} \qquad (4)$$

In other words, simple additivity of individual discomfort ratings is assumed. It is emphasized that this results in an arbitrary numerical rating which does not indicate the amount of discomfort produced by the group of sources. That is, doubling the rating does not imply twice as much discomfort. However, larger values of G_T do represent less desirable visual situations. According to Fry's analysis, this method of computing discomfort ratings has considerable merit.

Values of $\omega/\bar{\omega}$ have been computed for the five experimental conditions and are listed in line 4 of Table II. These are plotted against the ratio comparison/BCD in Fig. 7 (solid circles). The values may be represented by a linear logarithmic relationship. This indicates that the summation of $\omega/\bar{\omega}$ for the luminaires is related to the experimentally determined ratio of brightnesses by the simple exponential function

$$G_T = \sum\left(\frac{\omega}{\bar{\omega}}\right) = 0.69\left[\frac{\text{Comparison}}{\text{BCD}}\right]^{1.81} \qquad (5)$$

The experimentally determined Comparison/BCD ratio for condition E is 0.99. That is, this lighting system is judged by this group of observers to be approximately average BCD. On the same basis,

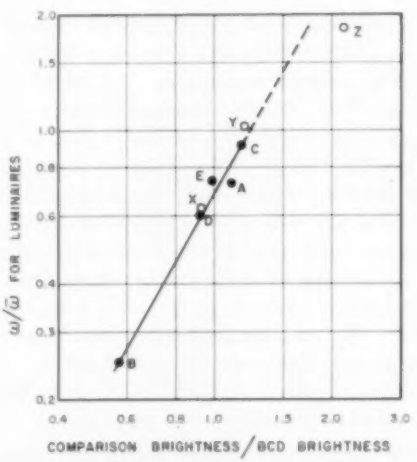

Figure 7. Relationship between observed values of comparison/BCD brightnesses and computed $\omega/\bar{\omega}$ ratings for the luminaires. Solid circles represent the five conditions of the present investigation. Open circles indicate three conditions from previous experiment.

the computed rating in terms of $\omega/\bar{\omega}$ would be expected to be equal to 1.0 if the group of luminaires is at average BCD. However, the computed ratio for this group of luminaires is 0.74, which indicates less discomfort than that experimentally determined. Theoretically, the two ratios should be expected to be equal. Such a difference can be caused by any one or more of a number of factors, such as subjective effects, or omitting certain unknown factors from the empirical formula. However, it is important to note that the computed relative ranking of the five conditions is the same as the experimentally determined ranking. It appears that the unknown factors apply consistently to all conditions. On the basis of Fig. 7, the ratio $\omega/\bar{\omega}$ is about 0.7 when the luminaires are judged to be at the borderline between comfort and discomfort.

As a matter of interest, three conditions studied in a previous investigation[3] are represented on Fig. 7 by the open circles marked X, Y and Z. Adjusting for differences between the two groups of observers, the subjective evaluations, in terms of the Comparison/BCD brightness ratios, were 0.93, 1.19 and 2.13, respectively. It is seen that two of the values plot very close to the relationship obtained in the present investigation. Even the highest value, Z, confirms that this particular lighting system was quite uncomfortable. In fact, according to Fig. 6, all observers would be expected to find it quite objectionable. Conditions Y and Z involve the same arrangements of luminaires as D and E, respectively. However, the average luminaire brightness of Y and Z is 590 footlamberts as compared with 375 footlamberts for D and E. Even though the wall brightnesses were proportionally higher, X and Y are indicated as being less comfortable than D and E. The general agreement between the two investigations is significant.

Similar computation of $\omega/\bar{\omega}$ for a number of the single sources used in previous investigations indicate that this ratio is less than unity for the average BCD sensation when an allowance is made for subjective differences. Such variations indicate the need for further research with additional lighting systems and with large groups of observers in order to develop a discomfort glare evaluation method which will be considered sufficiently reliable for practical application.

Conclusion

As previously indicated, the primary purpose of this paper is to describe a portable device which can be used for evaluating the visual discomfort produced by lighting systems. The data obtained with 50 observers show a consistent relationship with the basic BCD data. Furthermore, the relative discomfort evaluation obtained with five combinations of luminaires are relatable to computed ratings and are remarkably consistent. Confirmation of this relationship with additional lighting systems which include a wide range of relative discomfort should illustrate that a proposal of using the relationship of $\omega/\bar{\omega}$ as a measure of discomfort has considerable merit. By obtaining BCD data with the Discomfort Glare Evaluator, it is possible to relate any observer to those who have participated in the laboratory investigations.

Since the same technique involving momentary exposure of sources has been used by Putnam and his associates,[6] the Discomfort Glare Evaluator should be applicable to evaluating street lighting systems. Preliminary tests with an earlier model of the Discomfort Glare Evaluator with experimental roadway lighting situations indicate much promise.

When more data are available, it may be possible to develop a subjective comfort-discomfort scale. Similarly, evaluations by large numbers of observers will serve to confirm the Visual Comfort Index method of presenting discomfort glare evaluations. Obtaining these additional data may seem to be a long task. However, this new evaluator for relating practical situations to fundamental laboratory data should simplify matters considerably.

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DISCUSSION

R. G. HOPKINSON:* There are many features of this paper which call for admiring comment and I would like to add my congratulations to that of the other discussers. Clearly, the work shows that the problem of the evaluation of glare sensation can be solved along classical lines, for what the authors have done is to devise a null method of evaluation such as has been shown in, for example, the measure of visibility, to give reliable and repeatable results. It should be relatively easy for observers without special training to use the evaluator, because its simplicity should permit an adjustment to the borderline between comfort and discomfort to be made in a lighting installation without any more difficulty than in a laboratory.

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I think it would have helped if the authors had recapitulated their previous work to tell us why the ratio of the comparison brightness to the BCD should necessarily be a measure of glare sensation. One could also suggest that the range covered by the present experiments is rather limited for a comparison of the Guth and the Fry methods of evaluation because most of the points lie in the middle of the plot. I would also hesitate to say, as the authors do, that either method gives a *measure* of discomfort — they produce a ranking order, but not a measure. But that is rather a matter of expression.

There are two basic approaches in this matter of glare evaluation, the null method which the authors have used, and the scalar method which we have used. By confining themselves to a single criterion, the BCD, the authors have to use a comparison method and they do not get as much information as that which is revealed by a multiple criteria method. In effect, the authors' observers are human meters calibrated with only one graduation on their scale, whereas ours have a scale covering the normal range of experience. Such subjects can assess directly, with precision, the degree of glare from a lighting installation without the need for an evaluator, but of course they must be skilled in the art. An alternative to the multiple criteria method which Mr. Bradley and I have been studying under IERI Project 59 is the direct numerical assessment of glare sensation magnitude. This method is in its early stages but looks promising.

Professor Stevens of Harvard University pioneered the use of this method for the evaluation of noise, and it has since been extended by him and by others into many other modalities. Its use for the determination of a numerical scale of glare sensation is a new step, but we hope it will prove useful.

I am glad that this recent work by the authors gives us a new distribution of observer sensitivity. The original group at Nela Park showed less variation from individual to individual than our own group of 75 observers. This new group, fortunately, shows a wider variation. One of the few matters remaining to be settled between one side of the Atlantic and other is this function of variance in observer sensitivity.

It would be useful to know the effect of the immediate surround against which the source of the evaluator is seen, because that might have a marked effect on the BCD settings. I would also be interested to know the variance of the BCD settings made by the observers in this study. In our studies of glare, we have found that the distribution of mean judgments can be expressed by a figure of 0.35 log footlamberts for a homogeneous population such as a group of engineering students, but that the distribution for a random selection of the general public is wider.

This paper undoubtedly represents a step forward in the study of the evaluation of visual comfort. With experience, the Guth-McNelis evaluator should be capable of considerable precision in its use, and I look forward to the authors' next report with great interest.

GLENN A. FRY:* This paper is an excellent contribution to our knowledge about glare. It appears to offer a very feasible way of introducing, into a given environment, a comparison glare source for evaluating discomfort.

In the basic studies, the backgrounds have been uniform. In the new technique, wall brightness is taken to be equivalent to the brightness of a uniform field. One should not be discouraged because the correlations are not perfect. We have yet to learn how to make allowances for the variations in brightness throughout the field.

WARD HARRISON:* I am much interested in the authors' presentation and particularly in their reference to the close correlation between their tests and Dr. Fry's formula, based on area, for the summation of discomfort glare from a number of light sources. If further investigation confirms this relationship, it may mean that finally we have arrived at an authoritative and accepted formula for the evaluation of discomfort glare.

In Table II, line 3, the authors have shown values for the various installations tested, in terms of BCD. For installation D the figure is .92, and for E, it is .99. Carrying these values over to Fig. 6 of the paper, it becomes evident that in the case of installation D, approximately 60 per cent of the observers judged the lighting satisfactory, and in the case of Room E, only 51 per cent were satisfied. These two installations were in the same room and were alike in every respect except that in D, half of the luminaires were turned off and the tests show that comfort conditions were thereby improved. Turning off half the lights is just what people have learned to do when they are forced to work under a lighting installation which is not comfortable; they forego needed footcandles in order to be less annoyed by the light sources. A well-designed lighting installation should be satisfactory to 90 per cent or more of the users, and under these circumstances, there is no tendency for people to deny themselves the lighting they need.

The Visual Comfort Index (VCI) evaluation has been in use for some time, and Mr. Meaker and I thought it would be interesting to compute the VCI of the two typical lighting installations, D and E of the paper. The computed values are 75 and 54, respectively, in comparison with the authors' evaluations of 60 and 51. In other words, the VCI ratings were somewhat more lenient than the authors', especially in the case of installation D. If the now well-established figure of .44 had been used for the exponent of surround instead of Holliday's .30, the VCI values would have checked even more closely.

H. L. LOGAN:** This Glare Evaluator is an ingenious instrument. Its development will aid in more ways than the inventors now suspect, the exploration of a very complex subject. It can be adapted, for example, to investigating the elusive quality of "pleasantness" in a visual scene. It may turn out to be more useful in that connection than in the investigation of visual discomfort.

The real visual world is far apart from the simplified abstractions of the laboratory, and although this instrument is an attempt to bridge the gap, it is based, in its present form, on the laboratory target. This is logical, but the discrepancies found seem to be more important and larger than the authors believe, and this may be partly due to the characteristics of the target.

The real visual world generates retinal gradients, which act as stimuli in addition to the photometric characteristics of the field of view. Two different visual fields that are numerically similar as far as photometric measurements are

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**Holophane Co., Inc., New York, N. Y.

concerned, may therefore cause different comfort responses. Using a non-gradient target as the standard for comparison may be something like comparing cats with dogs. However, it is the proper first step and will undoubtedly lead to more satisfactory comparison standards in the future.

The remark of the authors that aside from a small exponent difference, there is but a 20 per cent difference in coefficient, is puzzling. Comparing the original formula given by Dr. Guth[1] with his latest equation, there seems to be a 40 per cent difference. Perhaps the authors will clear this up.

1. Luckiesh, M., and Guth, S. K.: "Brightness in Visual Field at the Borderline Between Comfort and Discomfort," ILLUMINATING ENGINEERING, Vol. XLIV, No. 11, p. 650 (November 1949).

CHARLES H. REX:* The Evaluator developed by Dr. Guth and Mr. McNelis has been a valuable aid in guiding the work for the "Computation of Relative Comfort and Relative Visibility Factors for Roadway Lighting."[1] Realizing the urgency of field testing for visual comfort ratings under roadway lighting conditions, the authors built and delivered one of the first Evaluators to us for use on our outdoor facilities in Hendersonville, N. C.

It is my understanding that this Evaluator was conceived and developed in response to a request for field instrumentation to aid visual comfort ratings. Such a request was made several years ago on behalf of the IES Roadway Lighting Committee. Apparently, this development is another instance where roadway lighting has assisted progress in research and knowledge on interior lighting.

We have been using the Evaluator for more than a year in night tests on the main street of our Outdoor Demonstration Laboratory.[2] Twenty-six observers have made some 800 field observations of relative visual comfort ratings for representative roadway lighting systems involving mercury and filament lamps.

Numerical ratings for the visual comfort quality of roadway lighting is an impelling objective which fully justifies such night work. It is an essential step toward increasing the night use of the public investment in automotive transportation facilities. One of the advantages of this Evaluator is that it may be used to demonstrate and provide better understanding of the fundamental practicability of the BCD concept. We find that an observer sitting in an automobile readily adjusts the brightness of the flashing comparison source to the borderline sensation between comfort and discomfort.

Another advantage is that the driver-observer can appreciate the fact that the BCD brightness for a roadway lighting system increases with appreciably higher field brightness, including the brightness of the pavement background against which the flashing comparison source is being viewed. This improves the relative visual comfort ratio, unless accompanied by a corresponding increase in the combined brightness of the system luminaires. The latter may be increased within the limits of the relative comfort ratio without decreasing the relative visual comfort. In general, progress involves higher brightness at or near the pavement level, with lower brightness at the luminaire mounting level.

These examples are only indicative of the usefulness of the Evaluator in aiding comprehension of visual comfort principles and ratings which make night driving easy and pleasant for millions of drivers. Thanks to the authors for a significant accomplishment.

*Outdoor Lighting Department, General Electric Co., Hendersonville, N. C.

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S. K. GUTH AND J. F. MCNELIS:* It is always gratifying to authors to receive complimentary and encouraging comments on their work. Research is never-ending, and the points raised in these discussions certainly emphasize this. Furthermore, they key in with some of the many questions we have asked ourselves. Unfortunately, space limitations never seem to permit covering all aspects of a problem.

We are particularly interested in Dr. Hopkinson's comments because of his own long experience with discomfort glare research. His question as to why the ratio of COMP/BCD brightnesses should necessarily be a measure of glare sensation is well taken. We did not intend to give this impression. The ratio is a "discomfort rating" and, as such, indicates the ranking of a lighting system. A probability plot, such as Fig. 6 of the paper, could be used, as we have done in the past, to convert this rating into a more meaningful value which represents the percentage of observers who will find the system to be at BCD. On the other hand, the ratio could also be related to a subjective scale of sensation, similar to that devised by Holladay, or the multiple criteria used by Dr. Hopkinson. The ratio does have the advantage of enabling us to compare various lighting systems which incorporate many combinations of the variables involved. In other words, the ratios represent subjective evaluations of relative discomfort, but do not, by themselves, tell us whether one system is twice as glaring as another. Perhaps the direct numerical assessment of glare sensation magnitude which Hopkinson and Bradley are studying will provide means for converting these ratios into actual measures of magnitude.

Each method of evaluating glare, the null and scalar methods, have merit. In laboratory experiments, where the conditions can be varied at will, the scalar method can be used quite successfully, as has been demonstrated by Dr. Hopkinson. On the other hand, when evaluating a specific lighting system, one cannot change conditions, but must use a method which permits rating it as it exists. Furthermore, our single criterion BCD method has been extremely successful with naive observers. No training has been necessary. It is our understanding that the multiple criterion method does require considerable training.

Dr. Hopkinson seems to feel that our finding a slightly greater variation among observers is fortunate because it indicates better agreement with his own data. Actually, the differences between our 1949 and 1958 groups are not great. One observer of the present group exceeded the highest observer of the earlier group. At the low end, three observers fell outside the original group. However, this does emphasize the need for more investigations with large groups of observers.

The importance of the surround brightness against which the test source of the Evaluator is seen is illustrated by Fig. 5 of the paper. The comparison evaluations of each lighting system were made with the same surround as the BCD observations. As indicated in the paper, it was the far wall of the room and is part of the natural situation. In other words, this is a common denominator for both BCD and comparison evaluations.

*Authors.

Regarding the variance of the BCD settings, we found the standard deviation of the individual observers to be 0.27 log footlambert for our group of 50 observers. This is somewhat less than that reported by Dr. Hopkinson. However, of even greater importance is the standard error of the means which was found to be 0.037 log footlambert. The first is, of course, an estimate of the dispersion of BCD settings for individuals, whereas the second is an estimate of the variability associated with means of BCD settings for 50 individuals.

We agree with Dr. Fry that much has to be learned about how to deal with actual visual environments and their differences from many of the conditions used in experimental work. Indications are that the Discomfort Glare Evaluator can provide a means for relating the two.

Dr. Harrison's comparisons of the Visual Comfort Index values with our results further illustrates the agreement that can be obtained between computation and experimental data. Obviously, our knowledge of discomfort glare is far from complete, and certain empirical assumptions must be made when developing a method for computing glare ratings. However, as Dr. Harrison indicates, these assumptions can be based upon logic and sound judgment until more adequate fundamental data are available.

The suggestion of Mr. Logan's regarding "pleasantness" offers some intriguing thoughts. It may be possible to adjust the Evaluator brightness until it is as equally unpleasant as a visual environment. However, to use his own words, this would seem even more like comparing "cats with dogs." Many more factors are involved in "pleasantness" than in "discomfort," and many are of purely psychological and emotional character. A visual environment could be designed with complete absence of discomfort, for example, a uniformly illuminated hemisphere with no glare sources present, but it probably would be considered most unpleasant from the viewpoint of esthetics.

The use of a laboratory target in the Discomfort Glare Evaluator should in no way detract from its usefulness. This is an accepted method for obtaining comparative data and for relating one condition to another. Our instrument has been devised for evaluating direct discomfort glare. As we have pointed out, there are certain differences, such as brightness patterns, between laboratory and actual environments. The Evaluator should materially aid in determining how these differences need to be handled in a complete system of evaluation.

The apparent differences in the coefficients of our 1949 and 1958 formulas involve the sizes of test-sources to which they pertain. The earlier published formula was in terms of a source size of 0.0011 steradian. The present data are for a source size of 0.0004 steradian. A smaller size of source permits a higher BCD brightness, as is shown by our basic data, and this has been used for determining the coefficient shown in the present paper. Thus, the difference is 20 per cent.

We agree that many more than five lighting systems need to be evaluated in order to adequately compare the Evaluator data with the Fry method, or any other method, for computing glare ratings. The primary purpose of this paper was to describe the Evaluator and illustrate the type of data which could be obtained. We plan to continue our activities in this direction.

IES Lighting Data Sheets and the New Footcandle Recommendations

In June 1958, a new set of footcandle recommendations was adopted by the Illuminating Engineering Society. The new values, in most instances, are considerably higher than the superseded ones. This means that many of the IES Lighting Data Sheets published before June 1958 report lighting installations that do not meet present IES recommended practice, so far as the number of *footcandles on the task* is concerned.

It should be recognized, however, that the footcandle level provided is only one of several considerations that determine the quality and all-round adequacy of a lighting installation, and its suitability for recording in an IES Lighting Data Sheet. Visual comfort, brightness ratios, and the inherent appropriateness of the lighting system to the lighting application are equally important.

It is suggested, therefore, that IES Lighting Data Sheets issued before June 1958 may still be used with confidence as a guide to good lighting practice so far as *lighting techniques* are concerned. To determine whether the footcandle values indicated meet present recommendations, consult the footcandle tables published in the August 1958 issue of ILLUMINATING ENGINEERING and supplemented in the February 1959 issue, or in the third edition of the IES Lighting Handbook.

SUBCOMMITTEE ON LIGHTING DATA SHEETS
PUBLICATIONS COMMITTEE

LIGHTING NEWS

South Central-Southeastern Join Forces Regional Conference, Asheville, N. C.

Query: Are two hosts better than one for a Regional Conference? Delegates to the joint meeting of the South Central and Southeastern Regions could well say — definitely! There were other factors in its success, though, than the double-barrelled sponsorship.

The location, for instance. This, it would seem, had considerable influence on the nature of the meeting. Many features of the technical program were significant, but the over-all nature of the conference was a happy springtime experience. For one thing, it was held at the Grove Park Inn on the outskirts of Asheville, N. C., in April. For another, this beautiful mountain resort Inn was peopled exclusively with IES'ers attending the meeting, and their wives. This circumstance usually generates a one-big-house-party feeling. The fun they had will be long remembered by the 152 who attended, and Kodachrome slides of the dogwood, azalea, rolling mountain countryside and vast stone fireplaces within the Inn will remind them of it anyway.

Several national officers attended this conference. The regular IES Executive Council met at the Grove Park Inn the entire day prior to the conference, and all of the officers present stayed on for the Regional. Another pre-conference event was the bus caravan, ensemble, to Hendersonville 20 miles away where everyone attending the conference witnessed a demonstration of the street-lighting testing grounds there.

Following a breakfast meeting for incoming and outgoing officers of both Regions' Sections and Chapters, with both Regional V-P's serving as chairmen, the Conference proper opened officially on Thursday morning, April 23. Edwin Gill, Treasurer of the State of North Carolina gave the keynote address. Four technical sessions followed, during that day and the next, presenting an excellent program of papers (see details below).

MMILJ

Although this was only the second Regional Conference held, with seven to go, it should be safe to say that this will surely be one of the best of MMILJ contests. Others have had the same good organization as this (Southern's contest was excellently organized by Coy C. Jordan, Chairman), and others have had a good representation from their local groups. But Southern's had everything. Every Section and Chapter was represented and so were both classes (13 contestants in all), and the competition was terrific. There were, of course, two contests — one for each Region. Here's how it lined up, eventually:

Southeastern Region

Class I — Sara Perkins, Georgia Section, First Prize
Si Bell, Florida Section, Second Prize
Paul C. Butler, Tar Heel Section, Third Prize

(Continued on page 8A)

DOUBLE-BARRELLED Conference had two Regional Veeps: J. M. Gensburger (left), South Central; J. A. Banton (right), Southeastern. In center is opening session chairman, R. A. McMichael, Chairman, Suwannee River Chapter.

SOME of the high level speakers featured at the technical sessions of the Asheville Conference included, left to right: Wade Evans, Session Chairman; Jack Holzinger, Rambusch Decorating Co.; W. P. Lowell, Jr., Sylvania Electric Products, Inc.

HAPPY DAY! Winners for Southeastern Region's MMILJ contest are, photo at left, Ralph Bush for Class II and at right, Sara Perkins, Class I. President Taylor and V-P Banton present the prizes.

SOUTH CENTRAL REGION winners Edna Fortier (Class I, Residential, left) and C. D. Strahan (Class II, Commercial) receive checks and congratulations from President Taylor and Regional Vice-President Gensburger.

ATTENDANCE plaque for mostest from the farthest presented to Georgia Section Chairman Tom Haslam. This too was awarded during the banquet.

(Continued from page 7A)

Betty Clark (presented by Frank Yanaros as proxy), Southeast Florida Chapter.

Class II — L. Ralph Bush, Georgia Section, First Prize
Robert E. Faucett, Palmetto Section, Second Prize
Frank Yanaros, Southeast Florida Section, Third Prize
T. Lew Cordle, Tar Heel Section
Barney P. Best, Florida Section

South Central Region

Class I — Mrs. Edna P. Fortier, New Orleans Section, First Prize
Class II — Charles E. Strahan, Jr., Mississippi Chapter, First Prize
George Schroeder (presented by proxy J. M. Ber), New Orleans Section, Second Prize
Charles D. Hooper, Mid-South Chapter, Third Prize

(Continued on page 11A)

problem

An easily maintained, integrated fixture was needed for Welton Becket's dramatic "squares of light" ceiling in the lobbies and offices of Southland Life's spectacular 42-story Southland Center in Dallas.

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ACHILLES by Lighting Dynamics was specified for the lobby . . . and it's companion Apollo was used in the offices throughout the center. Achilles is a highly versatile fixture series ideal for this demountable acoustical ceiling--just as it is for countless other ceiling suspension systems. It's quickly installed with a drop-in installation and has easy maintenance with press-to-open catches and hook-on hinges. Durable, Bonderized and electro-static, high-reflectance finishes . . . FOR MORE COMPLETE INFORMATION, call your Lighting Dynamics representative, or write to Lighting Dynamics, 802 West Whittier Blvd., Whittier, California or Lighting Dynamics, 8700 Ambassador Row, Dallas, Texas.

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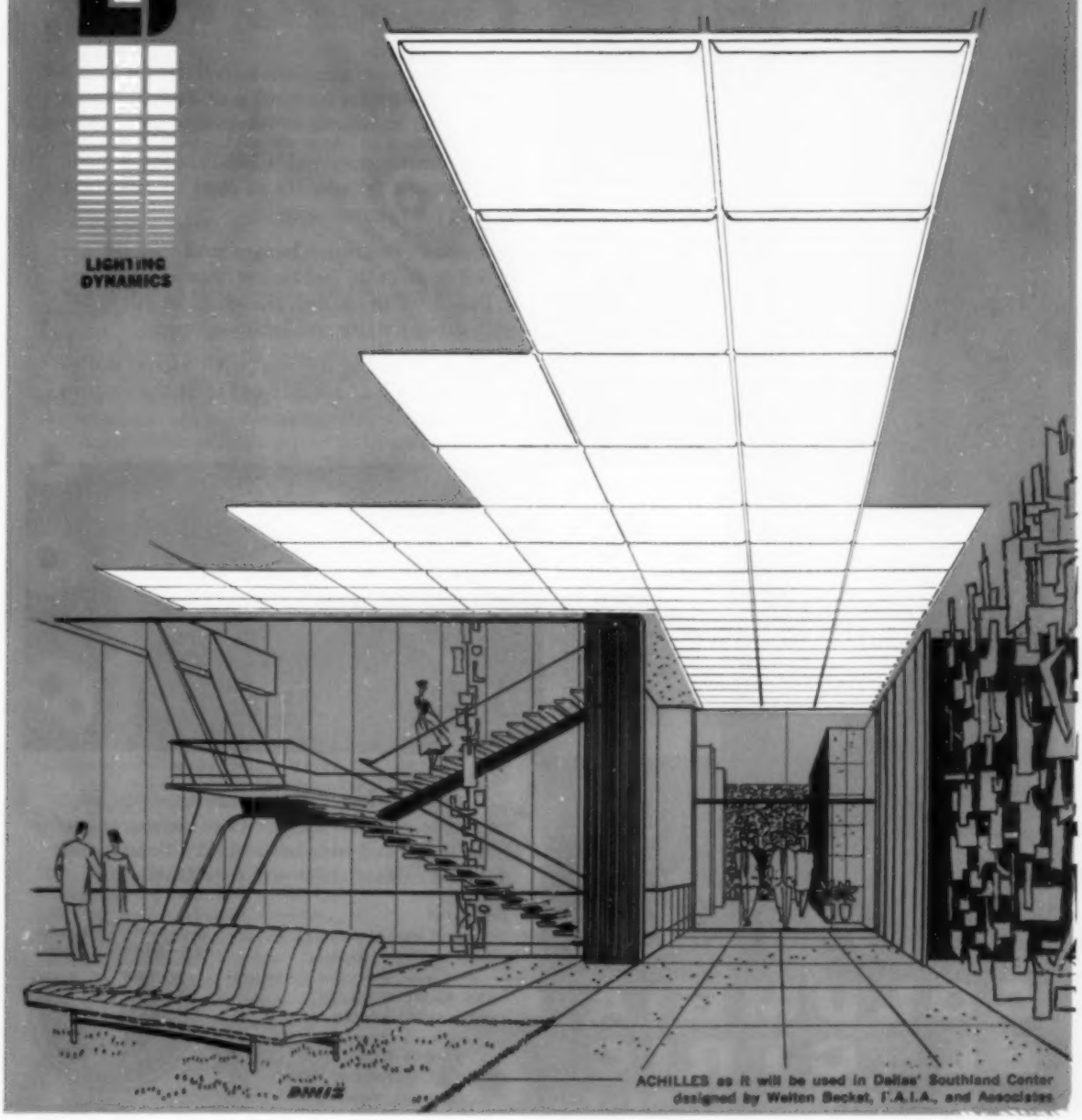

ACHILLES as it will be used in Dallas' Southland Center designed by Welton Becket, F.A.I.A., and Associates

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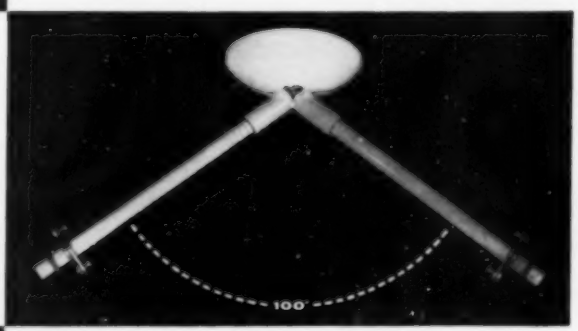

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PRESIDENT'S Message by George J. Taylor during a memorable luncheon session. Sharing head table with him are officers and conference speakers, l. to r., J. A. Banton, Jan Reynolds, C. Frank Dean, M. L. Harkey, Kirk Reid.

(*Continued from page 8A*)

Entertainment

With a house-party set-up, almost everything is entertaining. Bridge on the verandah, morning coffee alongside the pool, strolls down the azalea trails. As if all this weren't enough, however, the Committee (Walter Schwanhausser, General Chairman; A. D. Harrington, Entertainment Chairman), had an excellent program of social events as well.

On Wednesday afternoon, for instance, all sessions ceased so that the entire conference, ladies and delegates, could visit Biltmore, the fabulous Vanderbilt Estate some 20 miles distant. These wonderful formal gardens were never more photographed.

That same evening, dinner was a planned affair — a hot-dish buffet scheduled for tables on the lawn over the pool area. Chilly weather drove this indoors but red-checked table cloths preserved the informal party atmosphere. From dinner, the entire conference moved to the Laurel Room to see the Progress Report "Reaching for the Sun" presented by E. A. (Red) Linsday.

This wasn't all, for Wednesday evening. After the Progress Report, entertainment in the Great Hall of the Inn — with its enormous stone fireplaces at either end — was by North Carolina mountain children *clogging* through square dance changes. Later, the children, both boys and girls, chose partners from the IES audience and guided them through the dances, the children's little feet still clogging through every step.

On Thursday evening, entertainment was a Reception for President and Mrs. Taylor on the terrace, followed by a banquet and dance. The "family-party" feeling had completely taken over by this time. Chairman Schwanhausser's birthday (on this date) was celebrated by all 152 IES'ers present, awards were cheered to the rafters, the dancing party was especially gay. In addition to MMILJ prizes and the attendance plaque (won by Georgia Section), the banquet was the event for one other presentation, a gift from both Regions to President and Mrs. Taylor. This was silver cuff links made with local stones, to Mr. Taylor; earrings, ring and bracelet of local craft in dogwood design, to Mrs. Taylor.

The ladies, of course, enjoyed additional entertainment, ensemble. They breakfasted together each morning, as a starting point for local tours. In addition to those shared with the men (above), these included tours through craft shops, homespun mills and local shops.

Technical Sessions

For the record, the program was as follows:

Wednesday, April 22

IES Executive Committee Meeting.
Informal Dinner.
Crossroads of Light — Trip to Hendersonville, N. C.

Thursday, April 23

Regional Activities Breakfast Meeting — J. A. Banton, J. M. Gensburger, Chairmen.

Morning Session

Opening Session — Ray A. McMichael, Chairman, Suwannee River Chapter, Presiding.
Keynote Address — Edwin Gill, Treasurer, State of North Carolina.
High Frequency Lighting Power Sources — W. H. Johnson, Westinghouse Electric Corp.
Lighting and Color — Jan Reynolds, Sylvania Electric Products, Inc.
Doings in the South Central Region — J. M. Gensburger, South Central Regional Vice-President.
1958 and Southeastern Region—J. A. Banton, Southeastern Regional Vice-President.
President's Luncheon — M. L. Harkey, Chairman, Florida Section, Presiding.
President's Message — G. J. Taylor, President, IES.

Afternoon Session

Technical Session No. 2 — Wade Evans, Chairman, Coastal Empire Chapter, Presiding.
Engineered Architectural Lighting—Jack Holzinger, Rambusch Decorating Co..
Outdoor Applications of High Intensity Fluorescent Lamps—W. P. Lowell, Jr., Sylvania Electric Products, Inc.
Conducted Tour—Biltmore Estate, home of the late George Vanderbilt.
Informal Dinner.
Reaching for the Sun — 1958 Progress Report, E. A. Linsday, Chairman, Progress Committee.
Entertainment — "Cloggers."

Friday, April 24

Morning Session

Technical Session No. 3—H. O. Fellers, Chairman, Palmetto Section, Presiding.
Challenges in Outdoor Lighting — W. E. Schwanhausser, General Electric Co.
MMILJ Contest — Coy C. Jordan, Chairman.
Luncheon — Roy A. Palmer, Presiding.
Times Are Changing — C. S. Reed, Vice-President, Duke Power Co.

(*Continued on page 12A*)

PROGRESS REPORT and its smashing climax (shown here, Progress Committee Chairman Red Linsday and Mrs. Hughette Hawks of Hendersonville, N. C.) was an evening session, April 23.

COFFEE AND DANISH — Some of the 39 ladies who breakfasted together each morning in Asheville.

(Continued from page 11A)

Afternoon Session

Technical Session No. 4 — T. W. Haslam, Chairman, Georgia Section, Presiding.
Illuminating Engineering Research Institute's Program — C. L. Crouch, Secretary, IERI; Technical Director, IES.
Dimming Incandescent and Fluorescent Lamps — R. A. Langer, Kliegl Bros. & Co., Inc.
President's Honorary Reception.
Banquet — MMILJ Awards.
Dance.

Credits

The excellent program described should be credited to the following:

CONFERENCE COMMITTEE

General Chairman	W. E. Schwanhausser
Budget	A. M. Bjontegard
Decorations	John Kronenfeld
Entertainment	A. D. Harrington
MMILJ Contest	C. C. Jordan
Papers and Program	J. A. Lowe, J. W. White
Publicity	J. C. Boyter
Reception	E. G. Wendling
Audio-Visual Aids	J. S. Lindsay
Secretary	R. E. Faucett

PICTURES at this conference are by Berlon Cooper, *Electrical Construction and Maintenance*, shown (right) with President Taylor.

"Plasma" Described as Source For Electric Power

A method of lighting whole cities with small, efficient generators, operating by shooting electrons and ions through a magnetic field, was described recently in a paper presented before the American Physical Society. Dr. Joseph L. Neuringer, Republic Aviation Corp. scientist, said that electricity can be generated by forcing an electrically conducting plasma (a gas broken into electrons and ions) through a strong magnetic field, with efficiencies as high as those of any known power generation method.

With intensive research and development, large-scale plasma generators could become a reality within five to ten years, Dr. Neuringer predicted. As much as 1,000,000 watts could be generated by shooting a stream of plasma at speeds three times that of sound through a magnetic field only three feet long with the poles six inches apart, the scientist said.

While the investigations are theoretical, small amounts of electricity from plasma have already been generated.

Architectural Student Contest Launches Lighting Program

The announcement of 20 student architect winners in the Light for Living Medallion Home competition has launched the $500,000 National Lighting program of the Edison Electric Institute. Objectives of the contest were to stimulate the creation and development of new lighting ideas and to acquaint architectural students with the latest developments in home lighting techniques and equipment.

The four top awards went to P. Connor Lee, Hamilton, N. C.; J. G. Bulcken, New Freedom, Pa.; W. C. McGee, Jr., Raleigh, N. C. and James F. Kluttz, Raleigh, N. C. Working drawings and specifications, based on the winning plans, will be made available to builders through local electrical utilities, for the construction of model Light for Living Medallion homes throughout the U. S.

33 Countries to Participate In IEC Madrid Meeting

Representatives from 33 countries, including about 50 from the United States, are expected to attend the 1959 meeting of the International Electrotechnical Commission, in Madrid, Spain, June 30 to July 10. These delegates will participate in the work of 30 IEC committees. Other technical committees of the organization will meet in Paris and London, June 22-30.

A new 30-page booklet describing the organization — what it is, what it does and how it works — is available free from the American Standards Association.

Russian to English By Machine Translation

Experiments in machine translation seem to point the way to a practical production of English text from Russian technical literature. These studies are being carried on with a high-speed electronic computer by the National Bureau of Standards for the Army Office of Ordnance Research.

The program first instructs the machine to change the words of a Russian sentence into a highly condensed form for matching in the glossary. The machine is then told to recognize the syntactical relations between the words. After this, it puts together the English words into a meaningful sentence. With the improvements and short-cuts that are expected to be developed in the programming, and by using such advanced computers as are now under construction, the cost may be reduced to no more than a human translator charges. Such trans-

(Continued on page 17A)

DOW | PLASTICS

Just announced . . . light-stable polystyrene hits new high in resistance to yellowing!

STYRON® 672 and STYRON 673

VERELITE

The introduction of Styron 672 Verelite and Styron 673 Verelite heralds a significant new advance in fluorescent lighting fixture materials. Both are new, light-stabilized formulations developed by Dow for such applications as light grids, diffusers, and folding curtains.

These new polystyrenes have been fully tested and proved. They exceed the specification adopted jointly by the National Electrical Manufacturers Association, Illumination Engineering Society and Society of Plastics Engineers. In light stability tests, for example, they exhibited a yellowing factor of 2.3 after 500 hours, well within the allowable maximum of 15. General purpose polystyrene formulations reach 15 after only 393 hours of exposure. Thus the non-yellowing characteristics of the Verelite formulations make them an excellent material for fluorescent applications.

Both Styron 672 Verelite, the molding formulation, and Styron 673 for extrusion are now available in a wide range of granulations to meet varying requirements. For more information, return the handy coupon below for technical data and prices.

The addition of these two new polystyrenes brings the already extensive line of Styron formulations to a total of 15. Another milestone for industry's fastest growing group of polystyrene formulations.

THE DOW CHEMICAL COMPANY · MIDLAND, MICHIGAN

America's First Family of Thermoplastics

STYRON*

General Purpose
Styron 666
Styron 689 (Easy flow)

Medium Impact
Styron 330 (Easy flow)
Styron 777
Styron 369 (High heat)

High Impact
Styron 475
Styron 440 (Heat resistant)
Styron 440M (Easy flow)
Styron 480 (Extra-high impact)

Heat Resistant
Styron 683
Styron 700

Light-stable
Styron 672 (Verelite)
Styron 673 (Verelite)

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Please send me technical information and price schedule on Styron 672 Verelite and Styron 673 Verelite.

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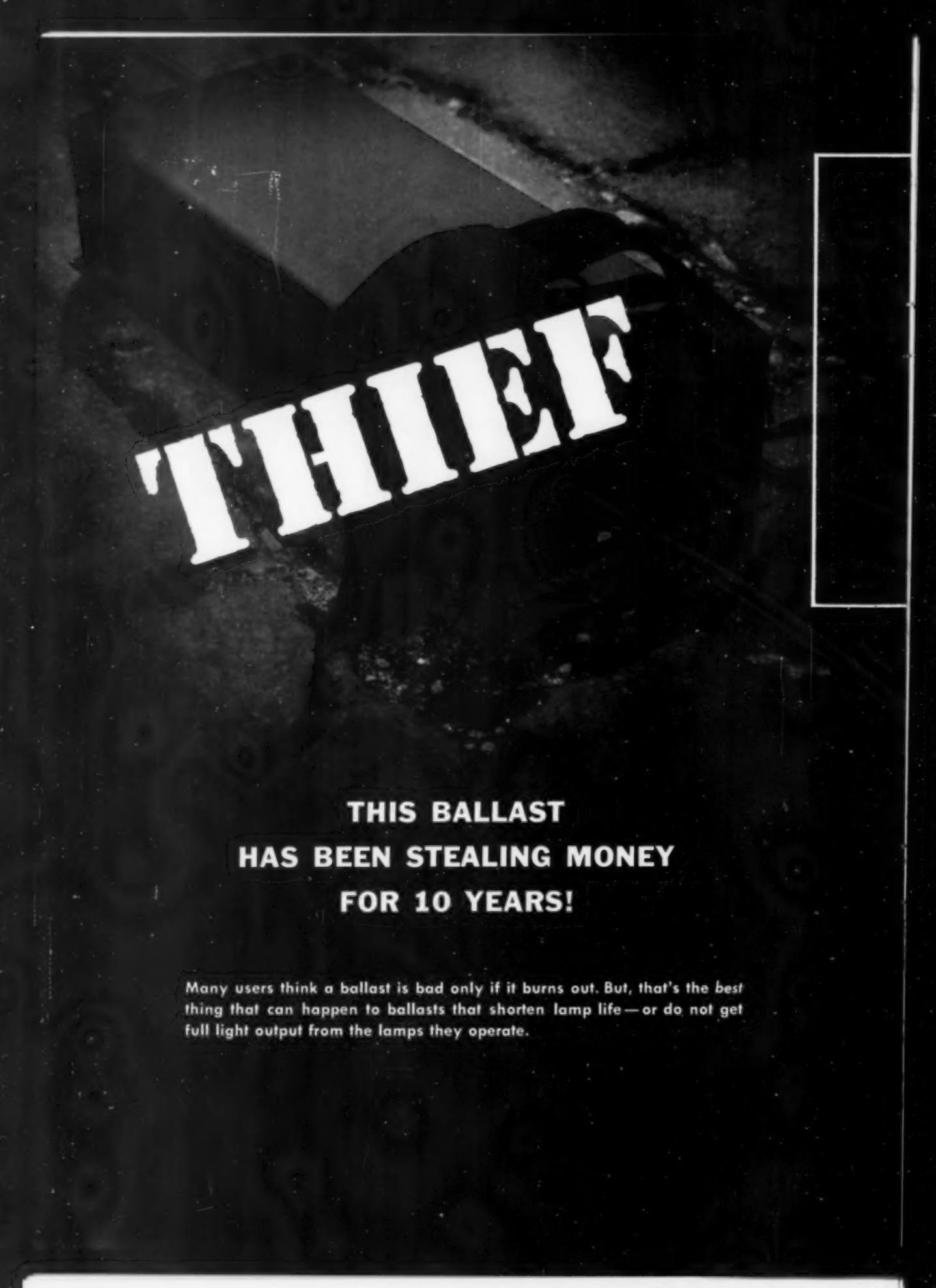

THIS BALLAST HAS BEEN STEALING MONEY FOR 10 YEARS!

Many users think a ballast is bad only if it burns out. But, that's the *best* thing that can happen to ballasts that shorten lamp life—or do not get full light output from the lamps they operate.

don't be robbed

of the light and lamp life you pay for

Get the honest quality of Jefferson CBM* Ballasts

Tests prove that inferior ballasts produce an average of less than 85% of their lamp's rated output—sending 15% of every lighting dollar down the drain. OR—the amount of light produced by EIGHT fixtures could be equaled by only SEVEN identical fixtures equipped with Jefferson CBM ballasts.

What's more, inefficient ballasts make lamps grow dimmer every day by "end blackening"—abnormal deterioration of the lamp cathodes—due to improper pre-heating by the ballast. Poor starting qualities of the ballast drastically shorten the life of the lamp.

Jefferson Ballasts treat the lamp right—for long life—maximum light output. With a Jefferson ballast in your fixture you're *assured* full rated output from the lamp. You're *assured* maximum life from the lamp because Jefferson ballasts insure proper starting and correct pre-heating to protect the lamp. You can get *more* light from *fewer* fixtures with Jefferson CBM ballasts.

Superior design and workmanship are your assurance that no other ballast is cooler or quieter—no other ballast will outperform or outlast a *Jefferson ballast!*

Jefferson Ballasts are available nationwide. Jefferson maintains fully staffed sales offices and warehouses in major cities—to offer you quick, competent service and assistance for standard jobs or individual specification installations.

*Certified Ballast Manufacturers Association

Write today for the complete Jefferson story

Bulletin B-1000: "Jefferson Ballast Data and Prices"

Bulletin B-1001: "Jefferson Fluorescent Ballast Comparative List"

Bulletin B-1002: "Jefferson Directory for Fluorescent Ballast Replacements"

Jefferson FLUORESCENT BALLASTS

Jefferson Electric Company — Bellwood, Illinois

Here and There with I.E.S. Members

Winner of Twin City Section's Allied Arts contest was Peter Lee, University of Minnesota architectural student, whose design for artificial and natural skylighting for a bank was demonstrated in the fully lighted scale model on table. Mr. Lee's name will be added to the list of winners of this annual competition on the IES plaque at the School of Architecture.

Professor Georges Destriau (center) was cited by Westinghouse for outstanding scientific achievement in his pioneer work on electroluminescence. Making the award to Professor Destriau, during his recent visit to the United States, are F. M. Sloan (left), Westinghouse Vice-President, and Dr. R. M. Zabel, Engineering Manager of the company's Lamp Division.

Class II (Commercial) winners in the Michigan Section's MMILJ contest were, l. to r.: Larry Beck (second from left), first prize; Hugh Nortemann, second; Bun Segall, third. Contest Chairman Albert Migdad is at far left; Section Chairman Adriaan van Oss, at right.

Panel members in the Montreal Section's Industrial Lighting Forum were, l. to r.: J. E. Shepherd, Section Vice-Chairman; Yvan Montcalm, Section Chairman; M. J. McAuliffe, Canadian Westinghouse Co.; G. J. Taylor, IES President; T. C. Sargent, Sylvania Electric Products; J. I. Campbell, Canadian General Electric Co. and IES Director Joe Thomas, Canadian General Electric. Missing from picture, but also on panel was B. J. Monaghan, Northern Electric Co. The Forum followed a joint luncheon meeting of the Section and the Electrical Club of Montreal. President Taylor, featured luncheon speaker, addressed the group on "Highlights of Illumination, Today and Tomorrow."

(*Continued from page* 12A)

lation may be neither elegant nor complete, but nevertheless it should convey the gist of the source material intelligibly and faithfully.

Feasibility studies have been carried out by Mrs. Ida Rhodes, a mathematician and linguist with NBS.

AIEE Celebrates 75th Anniversary

Some 500 representatives of industry, colleges, engineering societies and the press in the New York City area gathered at a luncheon May 13 at the Hotel Astor to celebrate the 75th anniversary of the founding of the American Institute of Electrical Engineers, on May 13, 1884.

Speakers on the occasion were Walter P. Marshall, president of Western Union, who described some of the new electrical developments of today; L. F. Hickernell, president of AIEE and vice-president, engineering, Anaconda Wire & Cable Co., who traced the history of the Institute. W. T. Rea, chairman of the New York Section of the group, acted as master of ceremonies for the program.

Two-Part Extension Meeting Sponsored by Milwaukee Section

Members of the Milwaukee Section of IES this year journeyed to Neenah and Appleton, Wis. for their annual extension tour and joint meeting with IES'ers from the Green Bay area.

The Neenah portion of the trip was devoted to a tour of the Kimberly-Clark plant and office building, with particular notice taken of the lighting. Dinner meeting at the Appleton Elks Club was highlighted by the presentation of checks and certificates to the MMILJ contest winners and a most apropos talk on industrial lighting by C. L. Amick, Day-Brite Lighting, Inc.

Seventy-seven members participated in the day's outing, 30 of them Green Bayers.

GUEST SPEAKER C. L. Amick, Day-Brite Lighting, Inc., discussing industrial lighting at Milwaukee Section's extension meeting in Appleton, Wis.

Charter Night Festivities For Central Florida Chapter

Central Florida Chapter, No. 85 on the IES rolls celebrated its formal entrance into the Society with a gala evening at the Elks Club, Winter Park, Fla. Following cocktails and dinner, charter presentation, to Chairman Hugh Saussey, was made by Southeastern Regional Veep, James A. Banton. Proxy for the handing over of the traditional gavel from the next youngest Chapter (Arrowhead, San Bernardino, Calif., in this case) was Martin Harkey, Chairman of the parent Florida Section.

Well-wishers and interested people from the surrounding area swelled the attendance to 80, and made for an interesting group of speakers. For example: J. D. Mitchell, IES Director; A. P. Michales, incoming Vice-President of the Florida Engineering Society; representatives from three utilities serving the area, a local architect and, bringing a lady's view on lighting, Mrs. Marion Walker.

With the installation of officers, always a part of charter night agendas, the following took charge of the Chapter's future: Hugh Saussey, Chairman; Ray Schad, Vice-Chairman; Lowry B. Miller, Secretary; Lee Stuhl, A. T. Folsom, Norris Upson, Bill Matten and George Yucius, Board of Managers.

Enthusiasm is high in Chapter No. 85,

(*Continued on page* 21A)

SCHEDULED EVENTS

June 18, 1959 — Council Meeting, Illuminating Engineering Society, New York, N. Y. Members are free to attend meetings of Council as guests.

June 22-23, 1959 — Great Lakes Regional Conference, Lafayette Hotel, Buffalo, N. Y.

June 22-24, 1959 — American Society of Refrigerating Engineers (Annual Meeting), Lake Placid Club, Lake Placid, N. Y.

June 22-26, 1959 — American Institute of Architects, Annual Convention, Hotel Roosevelt, New Orleans, La.

June 22-26, 1959 — American Institute of Electrical Engineers, Summer and Pacific General Meeting, Seattle, Wash.

Week of August 10. 1959 — International Association of Electrical Leagues, El Cortez Hotel, San Diego, Calif.

August 24-26, 1959 — International Association of Electrical Inspectors (Northwestern Section), Seattle Hotel, Seattle, Wash.

August 31-September 2, 1959 — International Association of Electrical Inspectors (Southwestern Section), Flamingo Hotel, Santa Rosa, Calif.

September 7-11, 1959 — National Technical Conference of the Illuminating Engineering Society, Hotels Fairmount and Mark Hopkins, San Francisco, Calif.

September 10-11, 1959 — Society of Plastics Industry, French Lick Sheraton, French Lick, Ind.

September 14-16, 1959 — International Association of Electrical Inspectors (Eastern Section). (Location unknown.)

September 14-17, 1959 — Institute of Traffic Engineers (Annual Meeting), Commodore Hotel, New York, N. Y.

September 25-26, 1959 — International Association of Electrical Inspectors (Canadian Section), Montreal, Que.

September 30-October 2, 1959 — Canadian Electrical Manufacturers Association, Sheraton-Brock Hotel, Niagara Falls, Ont.

October 5-7, 1959 — International Association of Electrical Inspectors (Western Section), Schroeder Hotel, Milwaukee, Wis.

October 5-10, 1959 — Society of Motion Picture and Television Engineers, Hotel Statler, New York, N. Y.

October 11-16, 1959 — American Institute of Electrical Engineers (Fall General Meeting), Chicago, Ill.

October 12-14, 1959 — International Association of Electrical Inspectors (Southern Section), Heidelberg Hotel, Jackson, Miss.

October 12-14, 1959 — National Electronics Conference, Inc., Hotel Sherman, Chicago, Ill.

October 12-16, 1959 — American Institute of Electrical Engineers, Fall General Meeting, Chicago, Ill.

October 13-15, 1959 — Electrical Progress Show, Convention Hall, Philadelphia, Pa.

October 15-17, 1959 — National Society of Professional Engineers (Fall Meeting), Olympic Hotel, Seattle, Wash.

October 19-20, 1959 — Annual Meeting of the United States National Committee (C.I.E.), Nittany Lion Inn, State College, Pa.

October 20-22, 1959 — Tenth National Conference on Standards, The Sheraton-Cadillac Hotel, Detroit, Mich.

November 2-5, 1959 — Eleventh Exposition of the Air-Conditioning and Refrigeration Industry, Convention Hall, Atlantic City, N. J.

November 9-12, 1959 — National Electric Contractors Association and Fifth National Electrical Exposition, Miami Beach, Fla.

November 9-13, 1959 — National Electrical Manufacturers Association, Traymore Hotel, Atlantic City, N. J.

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Words and Music

...they go together!

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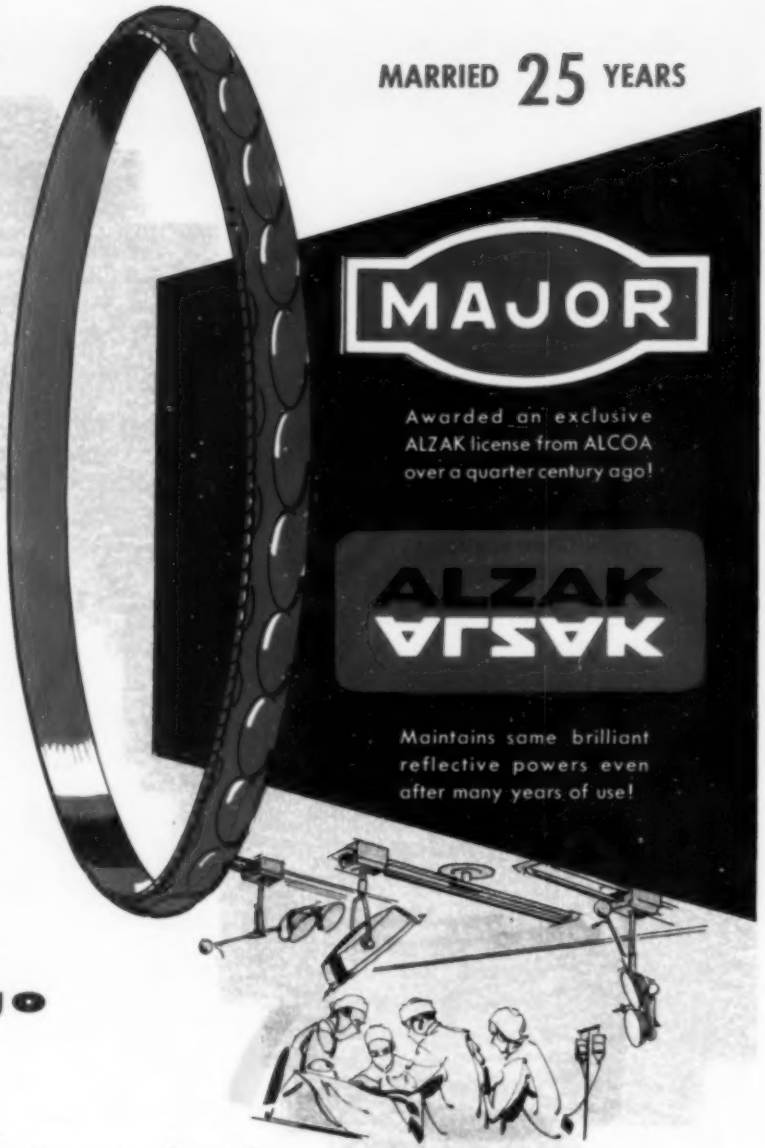
ALZAK

Maintains same brilliant reflective powers even after many years of use!



When Life and Death Hang in the Balance . . . They call for MAJOR-ALZAK* Reflectors!

You can duplicate the scene above in hospitals and dental laboratories all over the country. Because where absolutely *precise* lighting control is needed — and demanded — you'll find Major-Alzak reflectors. That's why they're used exclusively by manufacturers of Surgical and Dental lighting equipment.

Be sure that *you* play safe. Always specify Major-Alzak processed reflectors on your lighting jobs — whether inside or outside. They're vastly superior. They do not rust, tarnish, chip or peel. They outlast any other process. They give you far more brilliant all-around lighting results.

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We'd like to have you celebrate with us — send us your Name, Company Name and Address.

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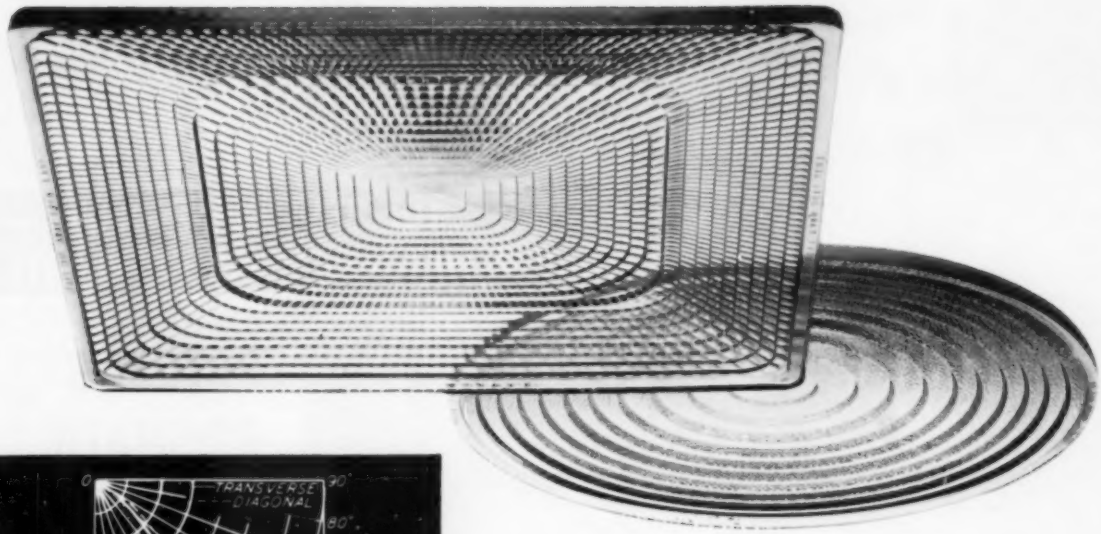
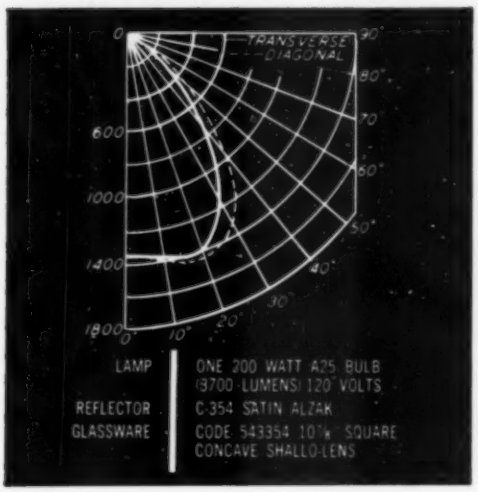
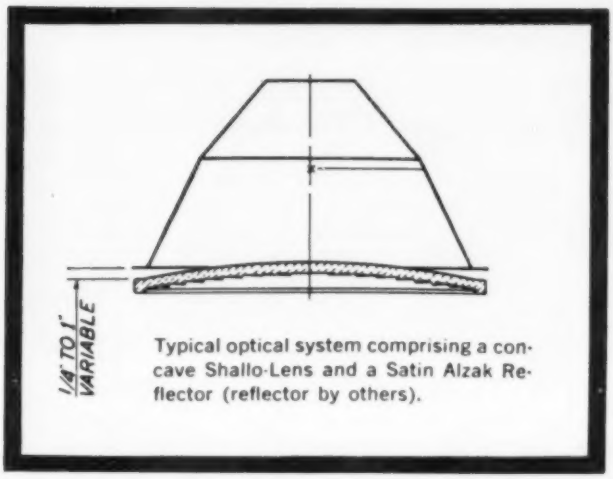




Notice low brightness in critical zones provided by this unique new optical design.



Typical optical system comprising a concave Shallo-Lens and a Satin Alzak Reflector (reflector by others).

New shallow effect can be achieved in incandescent fixtures with PYREX® Shallo-Lens and corresponding Satin Alzak Reflector in boxes six inches or less deep.

New from Corning
PYREX® CONCAVE SHALLO-LENS
for modern-styled incandescent fixtures

Nestled neatly in a mounting box six inches *or even less* in depth, this new Corning Shallo-Lens line can help you achieve with incandescent lighting the modern look in fixture design.

Coupled with a Satin Alzak Reflector, the Shallo-Lens gives you a new measure of uniform general illumination along with high efficiency and utilization.

Square and Round—Added diagonal intensity in the square Shallo-Lens fills in that area between units not normally illuminated by symmetrical distribution. The round design can be specified "Colouvered" for even softer illumination and lower brightness with risers glowing in the color specified.

Heat Resistant—Use this PYREX® heat-resisting glass indoors or out with no fear of breakage from excessive heat or sudden thermal shock.

For complete data on performance and design, write for Bulletin L-121-J. Address your card to Lighting Sales Department, 61 Crystal Street, Corning, N. Y.

CORNING GLASS WORKS

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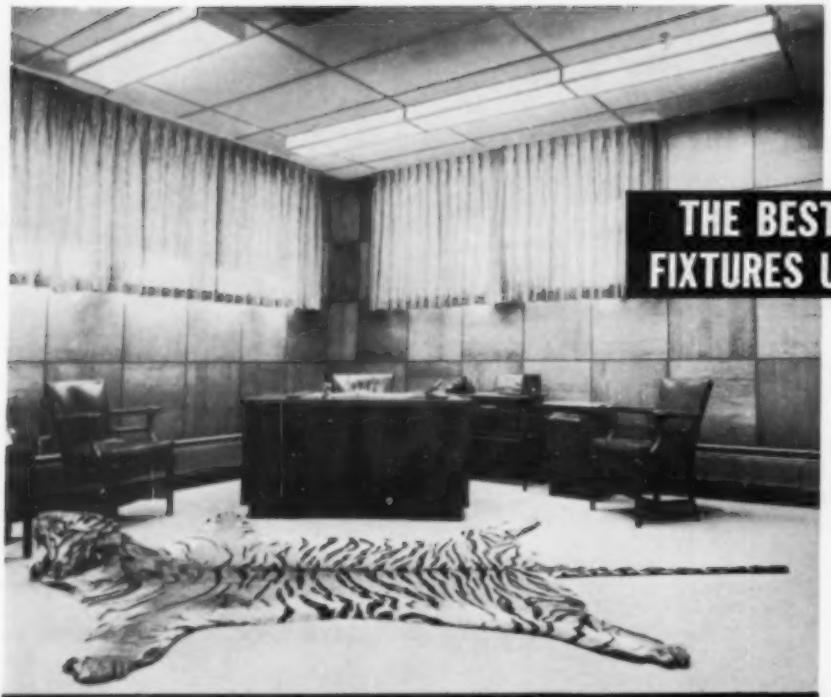

The recently-built plant of the New Era Mfg. Co., which specializes in multi-color flat-bed letterpress, prints any number of colors and completes in one operation all types of labels, tags, IBM and Remington Rand Punch Cards.

THE BEST BUY IN SIGHT — FIXTURES USING EXTRU-LITE®

ROTUBA'S PRISMATIC PLASTIC LENS

Plus

SYLVANIA'S FIXTURES

achieve new goals in quality lighting

The low 8 ft. ceiling of the President's luxurious office in the ultra-modern New Era Manufacturing plant, Hawthorne, N. J., strongly suggested the use of a shallow, close-to-the-ceiling fixture.

For luminosity as well as decor, several rows of **Sylvania's new rectangular Mohawk Fixture** were installed. See how attractively this slim luminous beam hugs the ceiling and follows the design pattern of the grid ceiling system and motif of the wood wall-paneling.

Extru-Lite*, the plastic shielding featured in this fixture, diffuses the light evenly and well, giving superior distribution with low brightness. The result is a soft, easy-on-the-eyes illumination. Architecturally and visually the perfect lighting solution for this room.

Throughout the plant, SYLVANIA'S lighting corresponds to the same high standards as in the chief executive's office.

Sylvania Troffers with Extru-Lite score with "pin-point illumination" at Warren Bowl, Warren, Ohio, the modern, wall-lit bowling alley.

SYLVANIA'S new recessed Troffers light a bowling alley effectively. One major advantage of using this Troffer paneled with Rotuba's prismatic plastic:— Extru-Lite affords the best benefits of high level illumination without blanketing the entire ceiling with lighting fixtures or luminous ceilings. The "pin-point illumination" that results is shadowless and glare-free putting no strain on the bowler's or spectator's eyes.

* Available in both Polystyrene or Acrylic.

THE ROTUBA EXTRUDERS, INC.

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(*Continued from page 17A*)

and the Society can look forward to much activity from these Floridians. Already being planned are a lighting course and Florida's first Residence Lighting Forum.

Central Kansas Chapter Chartered, No. 86

At the Council Executive Committee meeting held in Asheville, N. C. April 22, favorable action was taken on petition for a Charter to a new group in Wichita, Kansas. Approved as a new Chapter of IES (No. 86) was the Central Kansas Chapter. Petition was through Brooks Chassaing, Midwestern Region's Vice-President, who presented the charter at the Midwestern Regional Conference in Peoria, May 6-8. First Chairman of the new group is Carl Green, Carl Green & Associates, Wichita, Kans.

ASA Sets Up Gas Lighting Subcommittee

As a result of the re-introduction, in some fashionable neighborhoods, of decorative gas lighting for home exteriors, a new subcommittee of the American Standards Association is being formed to develop American Standard approval requirements for the safe and satisfactory performance of gas lighting. This action was taken by ASA Sectional Committee Z21 — Gas Burning Appliances, in March.

From the Desk of the President

On the page facing this column and elsewhere in this issue of IE are the sales messages of our advertisers, most of whom are close to the Society in many other ways as well. I commend to you the reading of these sales messages, because through them we are informed, every month, of all that is new in the way of lighting equipment, its special features and its usefulness as a tool of planned lighting.

As many of our readers will recall, advertising pages are comparatively new to the Society's magazine. From our first issue in 1906 until 1949, no regular advertising section appeared in our official publication. Since 1949, however, our advertisers' participation has helped to make ILLUMINATING ENGINEERING not only the outstanding lighting publication it is, but a national prize-winning technical publication as well.

I said the advertisers are "close to the Society in other ways." First of all, they represent the leading companies in every manufacturing branch of the lighting industry. Most of them, as companies, are Sustaining Members of IES and also have employees and principals in the individual membership. They participate in our standing, general and technical committees and are interested in lighting progress, research and development. These companies advertise in IE to keep IES members and other readers up-to-date on their new products. IE readers are key members of the lighting industry.

Perhaps you haven't seen the list of the important lighting business categories in which IE readers are employed. Here is the latest one, based upon a six months average circulation to December 31, 1958.

Architects	2197
Consulting Engineers	1048
Government Engineers	363
Industrial Engineers	333
Electric Utility Lighting Departments	2126
Electrical Distributors	956
Electrical Contractors and Contractor Dealers	583
Physicians, Professors, Students	862
Lamp Manufacturers	987
Lighting Equipment Manufacturers	1581
Portable Lamp Manufacturers	80
Accessory Equipment and Materials Manufacturers	1177
Miscellaneous	376
TOTAL	12,669

For that period, our membership averaged about 9100. Our other readers include paid subscribers, some in foreign countries, who pay $18 a year for their subscriptions. As a matter of record, IE goes to 40 countries outside of the United States and Canada, and while this distribution represents only a small percentage of the whole, it is important in that through these subscriptions IE has become a significant international influence in lighting.

Other IE distribution is to architects in the service areas of some 30 electric utility Sustaining Members who purchase IE in bulk for this service only. Thus, almost one-third of the monthly distribution of IE is to key individuals and organizations outside IES membership, people with an active professional interest in better lighting.

Many of you know, or have heard, of the tremendous increases in advertising rates in all types of media over the past ten years, due to increased printing costs, postage and all that goes into the making and mailing of a periodical. While it has been necessary to increase IE's rates in two easy stages of 10 per cent each since 1949, the cost for the advertiser to reach one reader or a thousand readers through the pages of IE has *decreased* in the same period, by 27 per cent, due to our steadily *increasing* circulation.

Advertisers in IE in this way get more quality mileage out of their advertising dollars. And, in this day, we would think this to be a mighty important consideration to other manufacturers of the in-

(*Continued on page 22A*)

GAVEL presentation at the Central Florida Chapter's Charter Night was by Martin Harkey (left), Chairman of the parent Florida Section, to Hugh Saussey, Chairman of IES' newest group. Pleased onlookers are, left to right: Lowry B. Miller, Secretary; A. T. Folsom, Board of Managers; James A. Banton, Southeastern Regional Vice-President; Ray Schad, Vice-Chairman; J. D. Mitchell, IES Director; Norris Upson and Bill Matten, both of the Board of Managers.

ARCHITECTURAL and lighting design for an elegant restaurant was the problem in the Allied Arts competition at the University of Southern California, co-sponsored by the Southern California Section of IES and the local Chapter of the American Institute of Architects. First prize of $100 was to Eugene Zellmer, fifth from left. Others who participated in the award ceremonies were, left to right, Roy Dahlin, member of National Allied Arts Committee; James Heaton III and J. Barry Moffitt, tied for third; Robert J. Little, second place; (Mr. Zellmer); Hal Johnston, meeting chairman; Bruce Corwin, Chairman, IES-AIA Committee; A. B. Gallion, Dean, USC School of Architecture.

(Continued from page 21A)

gredients of a good lighting job (whether they make fixtures, fixture components or accessories, or materials like paint, floor and wall coverings), who are not advertising regularly in your official journal.

GEORGE J. TAYLOR
IES President, 1958-1959

IT SEEMS TO ME

Ethics in Equipment Manufacturing

In my 35 years in the lighting industry, it seems to me that the one "glare factor" within the industry is the lack of integrity of those who serve no purpose other than to destroy the work of the honorable manufacturers whose designs and efforts have raised the industry, in general, to the high plane it merits.

We have the manufacturer who deliberately, or through lack of knowledge, misrepresents the performance of his equipment. Due to his activities, many of us have met with skepticism on the part of customers when we presented layouts. Some customers have the idea that all lighting men are congenital liars — this, of course, is not a fact; at least not all the time.

Manufacturers of this type are guided by *caveat emptor* — the excuse of swindlers — and are one day discredited but, meanwhile, destroy the customer's faith, the most valuable asset of any and all engineers, salesmen and manufacturers. Then we have the manufacturer who, I assume, would hesitate to steal the funds of his competitor, but who does not hesitate to steal the design of a fixture for which his competitor has created and developed a market. The excuse that the design is not patented (it would not deter some if it were) or is considered in the public domain is not valid as far as integrity is concerned. An unguarded bag of money in front of a bank might also be considered "fair game" but if you take it, you are a thief.

The "filching manufacturer" can, naturally, sell his unit at a lower price. He hasn't spent money on development and on advertising, and generally he makes it of cheaper material. I have a card from I. M. Fixman of Hub Electric Co., stating: "Nothing was ever made that somebody else couldn't make worse and sell for less." Too true.

Both these types of manufacturers may be considered sharp and shrewd but, in general, sharp and shrewd people are not men of integrity, and lack of integrity on the part of nations, employers, labor leaders and politicians is the cause of much of our troubles. Such men believe in expediency — the excuse of dishonest men — and as long as we have such men, just that long will honest men have to pay for and carry the brunt of evils created by those of questionable intelligence, integrity and intentions.

What can we do about them? I really do not know — after 35 years I have learned the answers to many things but not to this one, other than to let these "chiselers" know that by no measurement are they honorable nor are they a success regardless of what they may possess. Success is not what one gets, but what one becomes, and none has become very much who is a leech on the honorable and honored profession of illumination.

This may offend some; it is intended to. But I am sure it will not offend my friends — they are not of this ilk. PAUL E. BOWERS, *Buffalo, N. Y.*

ABOUT PEOPLE

Holophane Co., Inc., has announced the election of **Clarence C. Keller** as executive vice-president. Mr. Keller, who joined the company in 1929 as a test engineer, has served in various positions: manager of application engineering, sales manager and vice-president in charge of sales. He has been active in IES as Regional V-P, General Secretary, Director and Chairman of many committees, and is also a member of the Executive Committee of the National Lighting Bureau and Chairman of Sales Training Committee, National Electrical Manufacturers Association.

William H. Anderson was recently named to the newly-created position of electrical conductor specialist with the industrial market staff, Reynolds Metals Co., with offices in Houston, Texas.

Herman K. Gessner, formerly vice-president in charge of production for the Columbia Steel Equipment Co., has joined Melrose Lighting Co., Fort Washington, Pa. He will serve as Vice-President–Secretary.

Myles S. Gaythwaite has been named to the newly-created post of director of marketing — fixtures, Sylvania Lighting Products, a division of Sylvania Electric Products, Inc. He will be responsible for fluorescent fixture sales, marketing research, product planning, advertising and customer service, and will make his headquarters in Wheeling, W. Va. Since assuming his new position Mr. Gaythwaite has announced the promotions of IES Second Vice-President

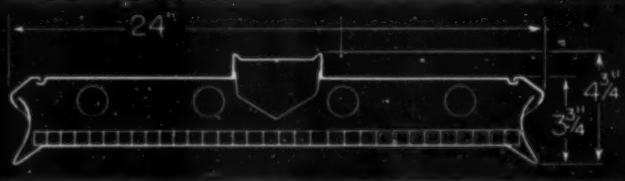
(Continued on page 27A)

the sculptured look in lighting

SCULPTURAMA

Here is a new, richly formed Visionaire® which, like today's architecture, fuses the functional with the aesthetic. Gently curved illuminated metal sides and refined styling give these surface-mounted luminaires a modern, sculptured look. The low brightness illumination from the sides make the fixtures "blend" smoothly with the ceiling. Application versatility is greatly enhanced by a choice of single-element, fully framed diffusers including the Sunbeam-exclusive SUNLUX plastic lens panel. The diffuser assembly opens from either side on full-length, invisible hinges. Installation and maintenance requires a minimum use of tools. Units available for 2 or 4-lamp rapid start operation.

For complete details write for bulletin #A84A.



SUNBEAM visionaire LIGHTING COMPANY

ENGINEERED FOR LONG BALLAST LIFE

SUNBEAM LIGHTING COMPANY • LOS ANGELES, CALIFORNIA • GARY, INDIANA

Sola Catalog No. 77-10-202
constant-wattage transformer for two H1, H25 or H33-1 400-watt mercury lamps—outdoor, weatherproof service

NEW

Sola outdoor mercury-lamp transformer is smallest, lightest two-lamp, constant-wattage unit

Reduced in weight from 70 to 48 pounds and in diameter from 8⅜ to 6⅝ inches, transformer Catalog No. 77-10-202 saves time, money and effort in shipping, handling, and installation. Improved operating characteristics result from a newly designed constant-wattage circuit combined with the use of Class-B insulation. Delivering ample open-circuit voltage for straight series operation of two 400-watt mercury lamps, the new model replaces series-sequence unit, Catalog No. 77046.

Performance improvements include a lower crest factor (peak/rms ratio) of lamp current. Reduction to a value of only 1.6 contributes to extended lamp life as well as high lumen maintenance over the lamps' useful life. Less than ±1% variation in rated lumen output — even with line voltage fluctuations as great as ±13% — results from the new circuit's improved lamp-wattage regulation. The new two-lamp unit has an efficiency of 90%, with a transformer loss of only 80 watts.

The housing is a single-piece, deep-drawn case . . . hot-dip galvanized and completely sealed. Special neoprene-covered leads are brought out through a neoprene plug in the threaded nipple. The new Sola mercury-lamp transformer is absolutely weatherproof and watertight.

Full engineering details and performance data are available in new bulletin MVO-359. Write for your copy to the Manager, Lighting Sales.

Sola Electric Co., 4633 W. 16th St., Chicago 50, Ill., Bishop 2-1414 • Offices in principal cities • In Canada, Sola Electric (Canada) Ltd., 24 Canmotor Ave., Toronto 18, Ont.

SOLA

CONSTANT VOLTAGE TRANSFORMERS

REGULATED DC POWER SUPPLIES

MERCURY LAMP TRANSFORMERS

FLUORESCENT LAMP BALLASTS

A DIVISION OF BASIC PRODUCTS CORPORATION

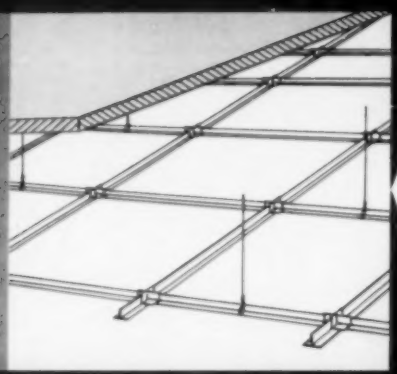
HERE'S HOW *Quiet-Light*

IS DIFFERENT . . BETTER . . MORE ECONOMICAL

IN CONVENTIONAL LIGHTING-AND-CEILING SYSTEMS:

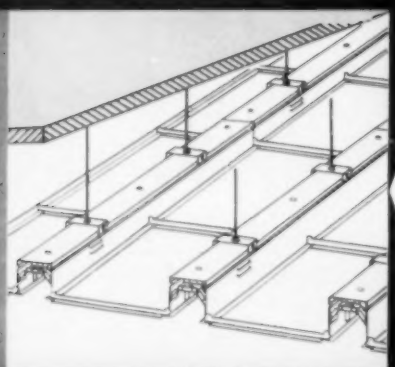
1

A separate framework of T-bars is suspended and cross-braced.



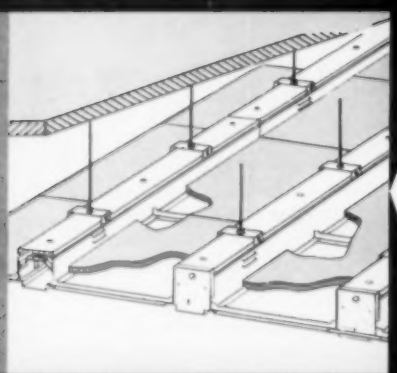
2

The lighting is suspended on this framework.



3

Acoustical panels are also suspended on this framework.



Quiet-Light

reverses the procedure and eliminates this step

1 **QUIET-LIGHT** recessed troffers are suspended by slide grip hangers, wall angles are mounted, and spacer bars inserted.

2 Acoustical panels are suspended on the framework created by the **QUIET-LIGHT** troffers, spacer bars and wall angles.

metco Lighting

NEMA UL evo-fi

QUIET LIGHT provides evenly diffused wall-to-wall quality lighting with efficient acoustics at decidedly lower cost. Write for catalog and specification sheet today.

SOLD ONLY THROUGH QUALIFIED ELECTRICAL DISTRIBUTORS

METALCRAFT PRODUCTS CO., INC., 6225 State Road, Phila. 35, Pa.

CLASS II "Oscars," proudly displayed by L. G. Leighton (left) and D. W. Prideaux, were awarded by the Academy of Motion Picture Arts and Sciences to these General Electric engineers for the development of a new 10,000-watt studio lamp. The new lamp, said to overcome the "blistering bulb" problems of the past, is reputed to give 16 per cent more average light over a 50 per cent longer useful life. Improvements were due to changes in lamp construction to accommodate a woven tungsten wire screen "collector grid" which controls heat and gas currents within the bulb.

(Continued from page 22A)

Richard G. Slauer from fixture sales manager to manager of marketing services, and **David E. Poor,** from supervisor of factory distribution to manager of customer relations. In another move, **Harold Barnum** was appointed manager of utility sales for the Division, with responsibility for the development of lighting products sales, advertising and merchandising programs directed toward the utilities. Mr. Barnum, who will have his office at the Division headquarters in Salem, Mass., will continue to be responsible for sales channels he handled as sales supervisor for mercury lamps.

Union Metal Manufacturing Co., Canton, Ohio, has announced the election of **L. F. Heckmann** as vice-president in charge of sales. Mr. Heckmann, who has been with the company since 1937, is Secretary of the IES Roadway Lighting Committee and active in the National Electrical Manufacturers Association, presently a member of their Executive Committee of the Street and Highway Safety Lighting Bureau.

Long Island Lighting Co., Mineola, L. I., has announced the election of **Charles Kiel, Jr.** as vice-president, operating services. Prior to this election, Mr. Kiel had been manager of the Operating Services Department.

Silvray Lighting, Inc., Bound Brook, N. J., has announced the formation of a new consumer division, to be headed by **Charles S. Schwarz,** former vice-president and general manager for L. & C. Mayers Co., distributors of merchandise for resale and prize-premium use. In addition to heading the new division, Mr. Schwarz will serve as director of merchandising and sales promotion for the firm.

John Jeffrey Hanna, former refinery manager of Imperial Oil, Ltd., Calgary, Alta., was elected President of the Engineering Institute of Canada for 1959-1960. Mr. Hanna was installed as President during the 73rd Annual Meeting of the Institute, June 8-10, 1959, Royal York Hotel, Toronto, Ont.

Better Light Better Sight Bureau has announced the appointment of **Lawrence P. Pleasants** to its Executive Committee. Mr. Pleasants, marketing development manager—lighting sales, Sylvania Lighting Products, succeeds **Garlan Morse** on the BLBS Executive Committee.

Effective May 1, **Carl L. Powell** has served as general manager, Western Division, Day-Brite Lighting, Inc. Mr. Powell, formerly marketing manager for the company, is now responsible for sales and manufacturing in eight western states and Hawaii. His offices are at the Day-Brite plant in Santa Clara, Calif.

John J. K. Shannahan was recently named assistant vice-president of the American Electric Power Co., New York, N. Y. Succeeding Mr. Shannahan as commercial manager for the Indiana & Michigan Electric Co., Fort Wayne, Ind., a subsidiary of American Electric Power, is **Nile W. Stiffler.**

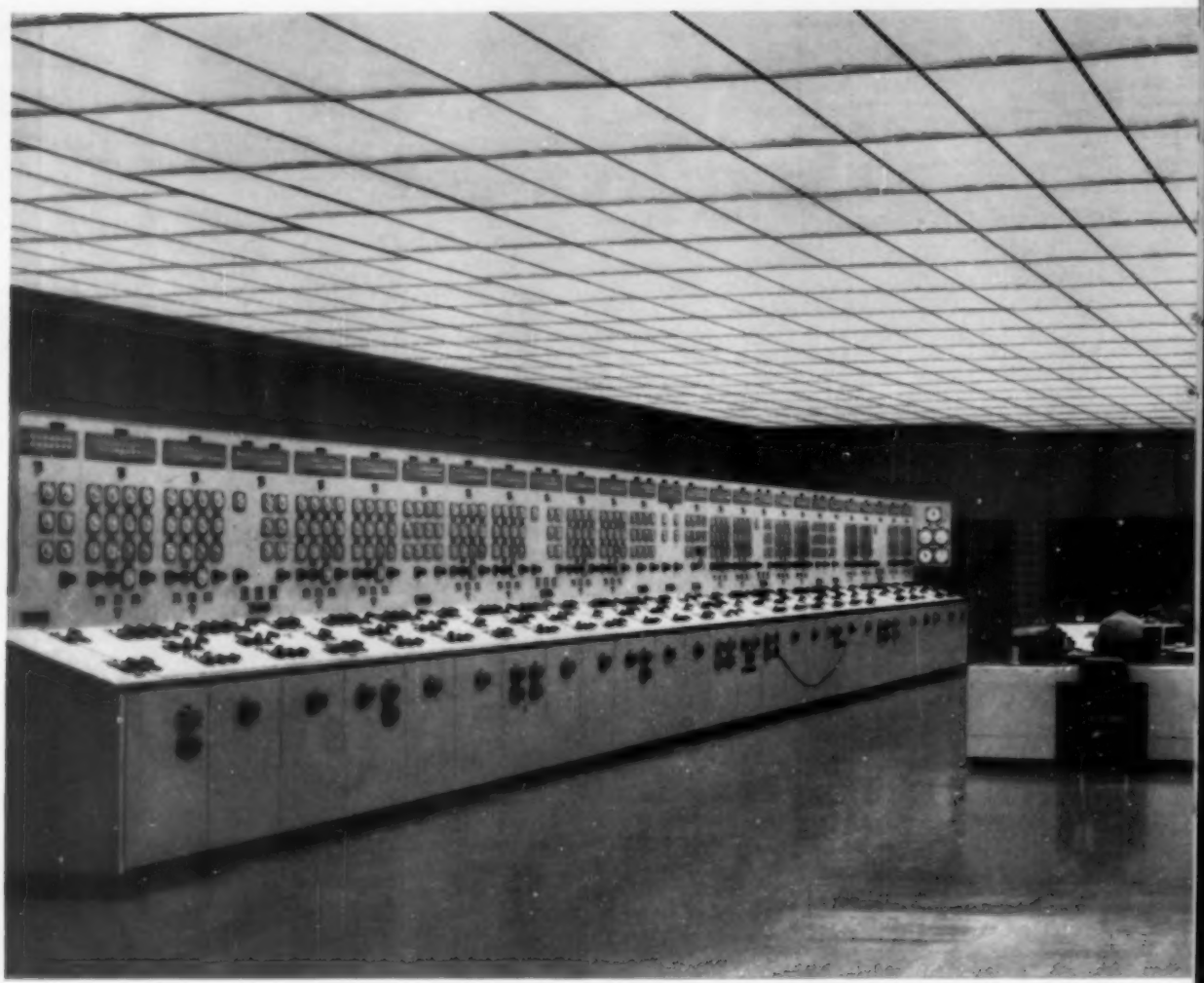
Progress Manufacturing Co., Philadelphia Pa., has announced the establishment of a Product Planning and Development Department, with **Julius Friedman** as manager. Mr. Friedman will have complete responsibility for all operations of the Department. In another announcement, the appointment of **Jack Fife** as member of **Block Brothers,** Detroit representatives for Progress, was made known. Mr. Fife will cover the territory of western Michigan and northern Indiana, from headquarters in Grand Rapids, Mich.

John C. Virden Co., Cleveland, Ohio, has announced the election of **Kim Moe** as vice-president—manufacturing. Since joining the company in July 1958, Mr. Moe has served as special assistant to the president. He was formerly associated with a residential lighting fixture manufacturer.

Arthur T. Higgins, Edison Electric Institute, New York, has been elected secretary of sectional committee C12 of the American Standards Association. This committee is concerned with the development of the code for electricity meters and is working under the sponsorship of the National Bureau of Standards, Association of Edison Illuminating Companies and the Edison Electric Institute.

N. J. McDonald, President of The Thomas & Betts Co., Elizabeth, N. J. has been elected chairman of the 1960 National Electrical Week committee. **R. M. Johannesen,** Johannesen Electric Co., Greensboro, N. C. will serve as vice-chairman, with **H. A. Webster,** T. Frederick

(Continued on page 30A)



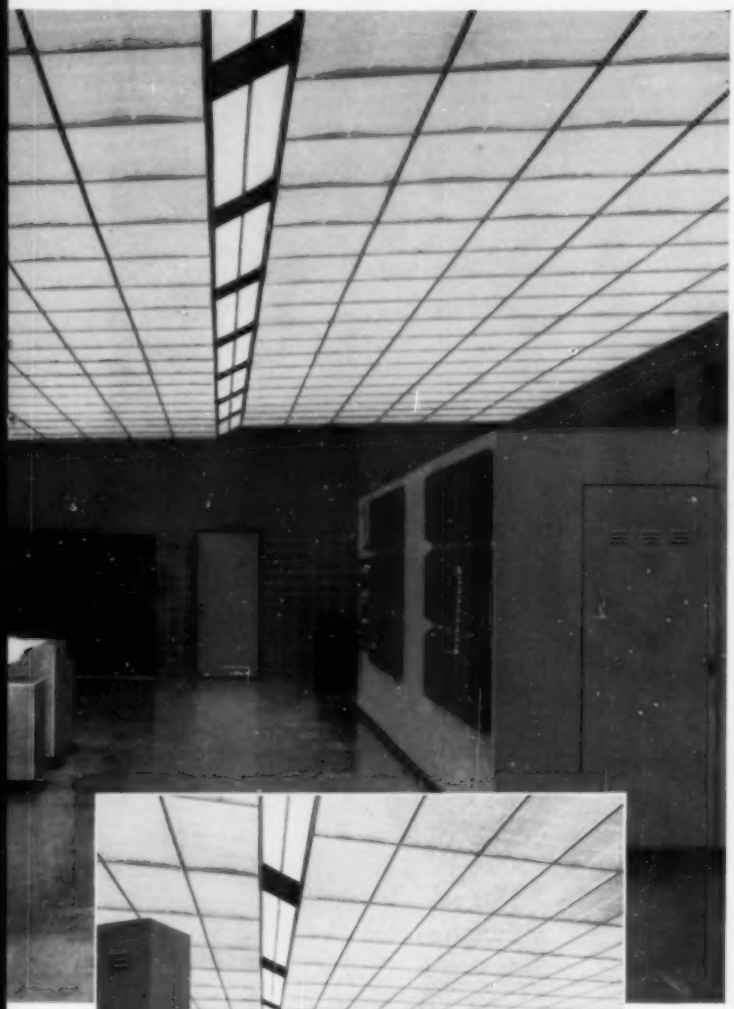
Photos Courtesy of the Power Authority of the State of New York

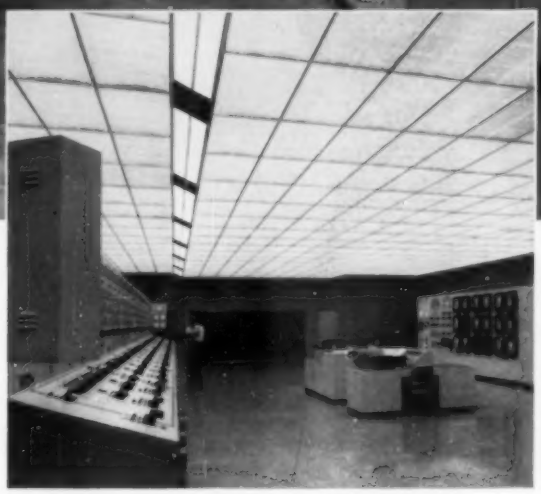
A Great "Team Job" of Functional Lighting

...WITH FIXTURES BY LITECONTROL

Challenging project, rewarding solution, beautifully functional. These six words sum up what may well be one of the most inspired lighting jobs of the year — the Control Room of the Robert Moses Power Dam, St. Lawrence Power Project. The engineers and the electrical contractor working with Litecontrol fixtures responded to the challenge and the result is self-evident.

One notes immediately the two ceiling levels which result from the tilted position of the board lighting troffers. These have asymmetric lenses which illuminate the boards and their meters *evenly* from top to bottom. Air conditioning outlets are designed into the row of





INSTALLATION:
Robert Moses Power Plant Control Room,
St. Lawrence Power Project,
Massena, New York

ENGINEERS:
Uhl, Hall & Rich, Boston, Massachusetts
(an affiliate of Chas. T. Main, Inc.)

GENERAL CONTRACTORS:
B. Perini & Sons, Inc.,
Sponsors of joint enterprise
Walsh Construction Company
Morrison, Knudsen Inc.
Peter Kiewit Sons Company
Utah Construction Company

ELECTRICAL CONTRACTOR:
Electrical Constructors, Columbus, Ohio

DISTRIBUTOR:
General Electric Supply Company, Buffalo, N. Y.

ROOM FINISHES:
Upper Walls — White, tinted Aqua Green
Lower Walls — Seaspray Green Ceramic Tile
Floor — Coralette Rubber Tile
Control Boards — Pale Yellow

CEILING HEIGHTS:
11′ — 3″ and 11′ — 9″

LIGHTING SYSTEM:
Litecontrol Lens Ceiling, using Holophane #6024 acrylic CONTROLENS®, with F40T12/WW/RS warm white rapid start lamps on dimmer controls, 24″ on centers. Board lighting — 2 lamp troffers, using Holophane #9010 asymmetric CONTROLENS® and F40T12/WW/RS lamps.

INTENSITIES:
Average, 30″ from floor, lamps on full, 152.8 footcandles. Lamps on ½ dim, 94.3 footcandles. Average vertical reading on face of boards, 75 footcandles; at edge of bench board, 55 footcandles. (All in service)

BRIGHTNESS:
Across axis of lens ceiling:
15° from horizontal, 150 footlamberts
30° from horizontal, 175 footlamberts
45° from horizontal, 200 footlamberts
90° from horizontal, 225 footlamberts

At supplementary troffers, across axis:
15° from horizontal, 339 footlamberts
30° from horizontal, 389 footlamberts
45° from horizontal, 425 footlamberts
90° from horizontal, 476 footlamberts

Figures courtesy Uhl, Hall & Rich
*Reg. Holophane Company, Inc.

troffers — these outlets and troffers are all supported by the lens ceiling structure.

Our lens ceiling with 880 Holophane acrylic lenses (about two feet square each), provides high intensity overall while keeping brightness exceptionally low. (See table.) It also eliminates reflected glare from the meter faces. Dimmers permit any intensity from the full 152.8, down to 2 footcandles.

This is a big lighting job, but our major interest at Litecontrol is not how big but how well. Can we help *you* on *your* next installation?

LITECONTROL
Fixtures
KEEP UPKEEP DOWN
LITECONTROL CORPORATION,
36 Pleasant Street, Watertown 72, Massachusetts

DESIGNERS, ENGINEERS AND MANUFACTURERS OF FLUORESCENT LIGHTING EQUIPMENT DISTRIBUTED ONLY THROUGH ACCREDITED WHOLESALERS

GRADUATION night for 67 of the students in the Florida Section's Advanced Lighting Course. Shown here receiving his diploma from M. T. Anthony (left), Vice-President in charge of sales, Tampa Electric Co., is graduate Jack Mason. At far left is Jack Boyle who presided over the evening's ceremonies. Photo at right shows some of the students (from 11 cities) attending one of the classes. Average attendance for the seven meetings was 71.

(Continued from page 27A)

Jackson, Inc., New York, as treasurer and **A. W. Hooper,** National Association of Electrical Distributors as secretary. National Electrical Week is celebrated during the second week of February, the birthday anniversary week of Thomas A. Edison.

Appointment of **Edward G. Bohler** as merchandise manager, with headquarters in Fort Atkinson, Wis., and **Donald Abwender** as northeastern division sales manager, have been announced by the Moe Light Division of Thomas Industries, Inc., Louisville, Ky. **Jerome T. Kurth** has been named factory sales representative in the Chicago area for the lighting fixture division of Thomas Industries.

Deaths

Garland R. Barlogi, Puget Sound Section

James Burt, Georgia Section

NEW MEMBERS

At the meeting of the General Board of Examiners on May 21, 1959, the following were elected to membership. Names marked * are transfers from Associate Member Grade. Names marked ** are transfers from Student Member Grade.

ALABAMA SECTION

Associate Member:
Sim, W. D., Clower Electric Supply Co., Inc., Mobile, Ala.

ALAMO SECTION

Associate Member:
Simons, M. G., 526 Aztec Bldg., San Antonio, Texas.

ARIZONA SECTION

Associate Members:
Cross, Robert, Arizona Public Service Co., Holbrook, Ariz.
Freridge, W. E., Arizona Public Service Co., Phoenix, Ariz.
Schwartz, Dan, Arizona Public Service Co., Phoenix, Ariz.

ARK-LA-TEX CHAPTER

Member:
*Hardaway, H. E., Westinghouse Electric Supply Co., Shreveport, La.

ARROWHEAD CHAPTER

Associate Members:
Anderson, W. G., California Electric Power Co., Victorville, Calif.
Bailey, C. E., California Electric Power Co., Palm Springs, Calif.
Isley, L. L., California Electric Power Co., San Bernardino, Calif.
Martin, Kermit, California Electric Power Co., Barstow, Calif.

Annual Meeting

In accordance with Article VIII Section 1 of the Constitution of the Illuminating Engineering Society, the Annual Meeting will be held in conjunction with the National Technical Conference in San Francisco. The Meeting will be held at 10:10 a.m. in the Opening Session of the Conference, Monday, September 7th, 1959, at which time the National Officers will report to the membership of the Society.

BLUENOSE CHAPTER

Associate Member:
Lee, Douglas, Triangle Conduit & Cable (Canada) Ltd., Armdale, N. S.

BRITISH COLUMBIA SECTION

Associate Member:
Ireland, L. D., Garcy Co. of Canada Ltd., Vancouver 13, B. C.

CAPITAL SECTION

Member:
Cooksey, H. L., U. S. Maritime Commission, Electrical Engineering Division, Washington, D. C.

CENTRAL FLORIDA CHAPTER

Associate Members:
Bagley, G. W., Jr., 516 E. Central Ave., Orlando, Fla.
Green, John, Florida Power Corp., Winter Park, Fla.
Olson, C. W., Jr., Olson Electric & Hardware Co., Daytona Beach, Fla.

CENTRAL ILLINOIS CHAPTER

Associate Member:
Best, R. M., Best Electric Co., Peoria, Ill.

CENTRAL NEW YORK SECTION

Member:
*Brown, D. R., Crouse Hinds Co., Syracuse, N. Y.
Associate Member:
Greene, R. H., Crouse-Hinds Co., Syracuse, N. Y.
Student Member:
Male, John, Cornell University, Ithaca, N. Y.

CHICAGO SECTION

Members:
Booton, J. F., Burnham & Hammond Inc., Chicago, Ill.
Danisch, E. A., Illinois Bell Telephone Co., Chicago, Ill.
McDonald, C. J., Multi-Electric Mfg. Inc., Chicago, Ill.
Associate Member:
Elliott, A. B., Jr., Jefferson Electric Co., Bellwood, Ill.

CHINOOK CHAPTER

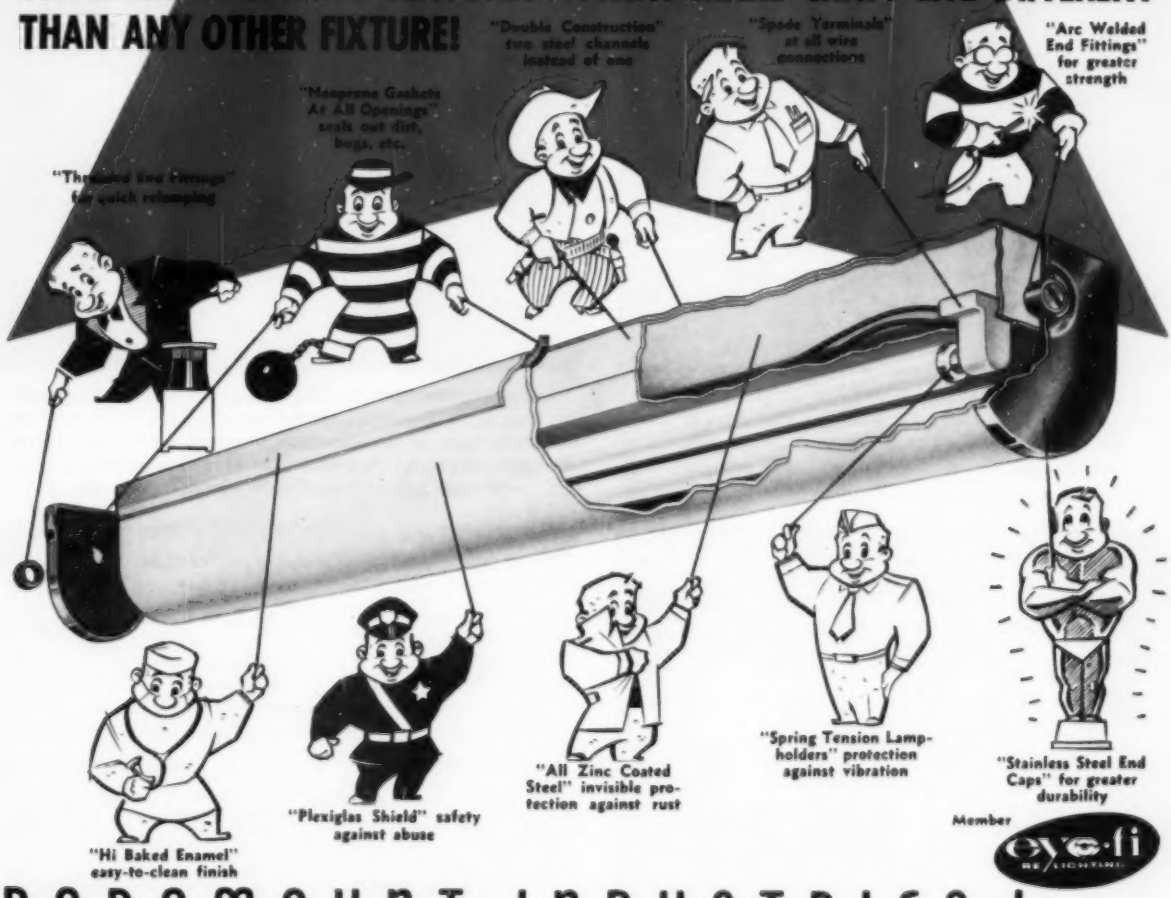
Member:
Willis, E. G., Haddin Davis & Brown Ltd., Calgary, Alta.
Associate Member:
Brown, E. E., Duro-Test Electric Ltd., Calgary, Alta.

(Continued on page 53A)

WHAT IS CRAFT LITE ?

PROTECTED LIGHTING!

WITH THESE QUALITY FEATURES...THAT MAKE CRAFT LITE DIFFERENT THAN ANY OTHER FIXTURE!


"Double Construction" two steel channels instead of one
"Spade Terminals" at all wire connections
"Arc Welded End Fittings" for greater strength
"Neoprene Gaskets At All Openings" seals out dirt, bugs, etc.
"Threaded End Fittings" for quick relamping
"Hi Baked Enamel" easy-to-clean finish
"Plexiglas Shield" safety against abuse
"All Zinc Coated Steel" invisible protection against rust
"Spring Tension Lampholders" protection against vibration
"Stainless Steel End Caps" for greater durability

Member eye-fi RE/LIGHTING

PARAMOUNT INDUSTRIES, Inc.

G-1080 BALLENGER ROAD FLINT 4, MICHIGAN

Manufactured in Canada by C & M PRODUCTS LIMITED, SCARBOROUGH, ONTARIO

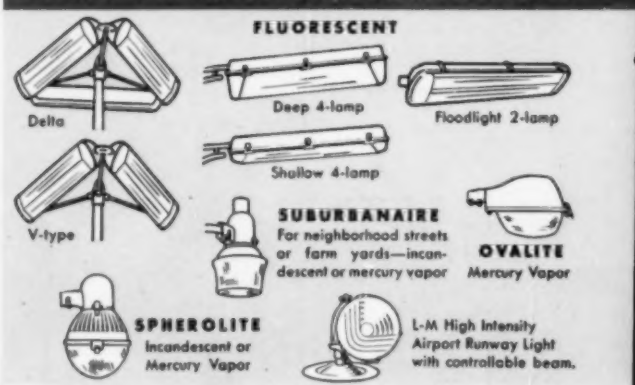
LINE MATERIAL FLUORESCENTS provide the lighting needed to attract customers to this shopping center, and to illuminate the parking area in front of it. The installation consists of deep four-lamp units, which provide ample light for display and security.

MOTEL OWNERS recognize the value of controlled lighting that lights up the approaches and driveways without disturbing glare. This owner selected L-M Ovalite luminaires, which utilize 21,000-lumen mercury vapor lamps to provide high-level illumination.

L-M FLOODLIGHT FLUORESCENTS provide excellent light for night operations on this loading dock, since the low brightness of the units will not blind the workers. Each unit contains two 6-foot fluorescent lamps with a total output per luminaire of 11,400 lumens.

INCANDESCENT-BURNING SUBURBANAIRE LUMINAIRES mounted on brackets from the building light the store front and parking area of this National Food Store. The warm light of the incandescents provides natural color for food items in the windows.

SOME TYPICAL L-M LUMINAIRES



LINE MATERIAL®
McGRAW-EDISON COMPANY

SPECIALLY DESIGNED LUMINAIRES in Rhondda Valley Shopping Center, Sunnyvale, Calif. This installation and the special units were designed under the direction of L-M Lighting Engineer Bruce Kunde, in cooperation with the designer, Robert M. Sherman, and Cupertino Electric Company, the electrical contractor. The two units on each standard are L-M floodlight fluorescents, holding two 6-foot lamps.

Streets, Shopping Centers, Airports . . . You Name It . . . L-M Will Light It!

Line Material, a pioneer and leader in outdoor lighting, provides incandescent, mercury vapor, fluorescent luminaires and related equipment for a wide variety of applications. Standard and special designs are available. L-M Lighting Application Engineers cooperate with utilities, municipalities, engineers, architects and contractors to help provide the most suitable, efficient, and economical equipment for each particular application.

The specially designed lighting unit in the Sunnyvale, Calif., shopping center shown above is an example of an unusual problem solved by one of L-M's Lighting Engineers, with the cooperation of L-M's engineering and manufacturing departments. The delta unit, shown at right, is also designed especially for area lighting.

Other fluorescent units include the V-type, which gives excellent street lighting; the 2-lamp floodlight, used for wall mounting on airport runways, loading docks, store fronts, etc. A wide variety of mercury vapor and incandescent units are used for highway intersection, toll road, access, neighborhood, and rural lighting.

Bring Us Your Lighting Problem

Whatever your outdoor lighting job may be, talk to the L-M Field Engineer or Lighting Engineer. You'll get suggestions, information, bulletins, and, if you wish, a complete lighting application engineering job. Or, if you prefer, write Lighting Division, Line Material Industries, Milwaukee 1, Wisconsin. In Canada: Canadian Line Materials, Ltd., Toronto 13, Ontario.

L-M's DELTA TYPE, especially suitable for area lighting, such as parking lots, shopping centers, etc. The unit consists of three 2-lamp floodlight fluorescent luminaires—with six 6-foot fluorescent lamps providing a total output of 34,200 or 55,800 lumens, depending on lamps used. Design of the reflectors assures high utilization of light output with a minimum of glare.

Industries Outdoor Lighting

McGRAW EDISON

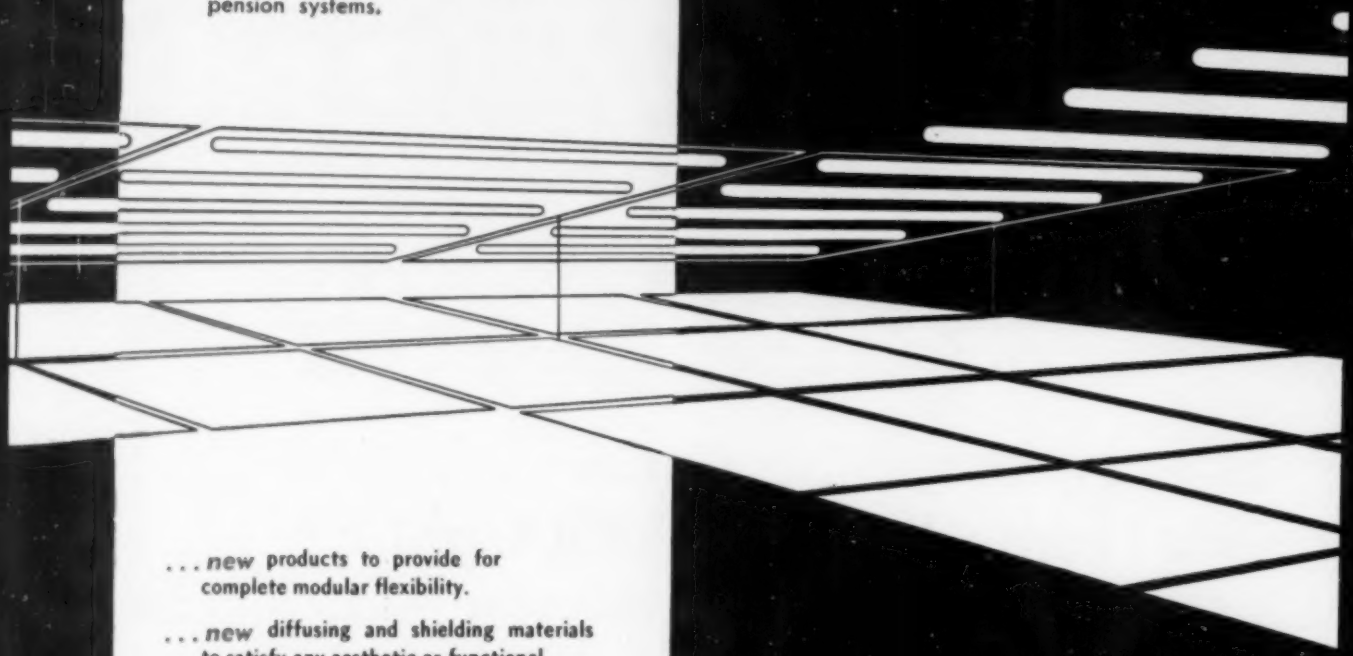
379

DISTRIBUTION TRANSFORMERS • KYLE RECLOSERS AND OIL SWITCHES • FUSE CUTOUTS AND FUSE LINKS • LIGHTNING ARRESTERS • POWER SWITCHING EQUIPMENT
PACKAGED SUBSTATIONS • CAPACITORS • REGULATORS • OUTDOOR LIGHTING • LINE CONSTRUCTION MATERIALS • PORCELAIN INSULATORS • FIBRE PIPE AND CONDUIT

aci ceilings inclusive

. . . a prime equipment supplier of all of the components, standard or special, which comprise total luminous *ceilings* —

— *inclusive* of all lighting material, diffusing and shielding media, and suspension systems.



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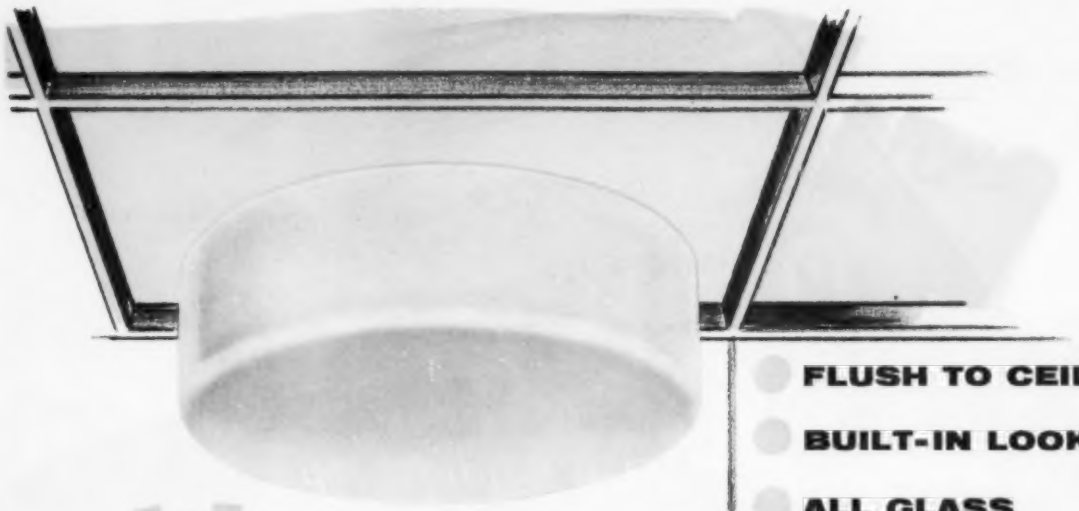

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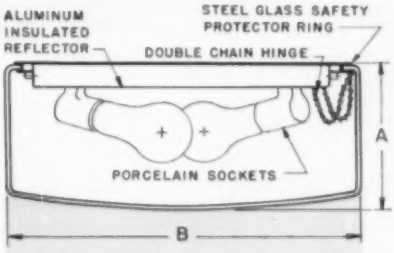

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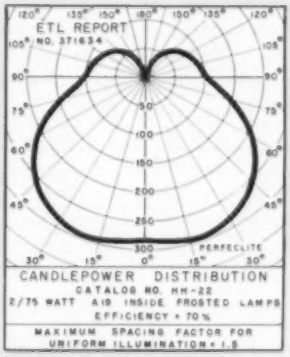

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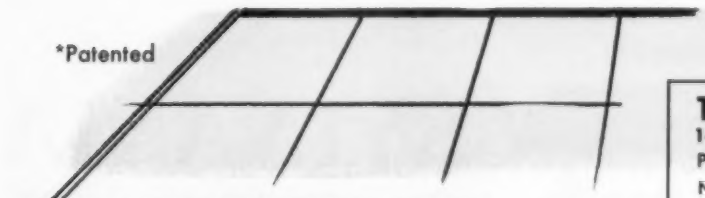

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To develop a completely fresh and different approach to lighting fixture design, Sylvania retained the services of the renowned industrial designing firm, Peter Muller-Munk Associates.

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Pendant mounting with diffused plastic panel

Close ceiling mounting with plastic louvers

The CLASSIC is *really* new . . . designed by experts to give commercial interiors a fresh, distinctive appearance together with outstanding illumination.

You'll like the sleek, trim lines and slim shallowness of this fixture . . . the flared, softly-diffusing side panels . . . the harmonious matching of plastic and metal . . . and the choice of three excellent shieldings.

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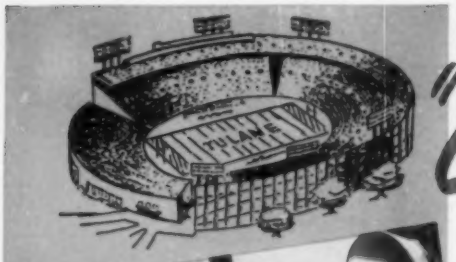
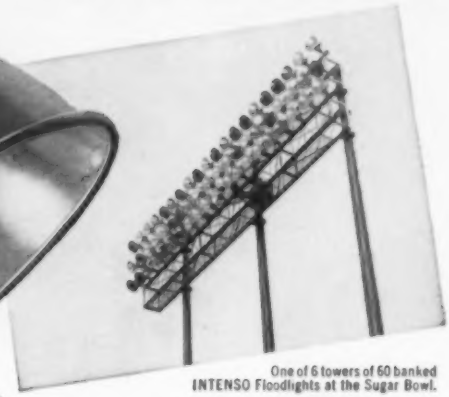


Workman at Sugar Bowl checking INTENSO light before bank is raised to lower height.

Photos courtesy of Tulane University

Mario Zervigon and Associates, Consulting Engineers

Opens for Split-Second Rear Relamping



One of 6 towers of 60 banked INTENSO Floodlights at the Sugar Bowl.

Outstanding Features of APPLETON INTENSO FLOODLIGHTS

- Sights like a rifle to assure easy positioning . . . even in daytime
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Unlighted for 30 years, the choice of lighting experts, maintenance and financial men at Tulane for illuminating the Sugar Bowl was APPLETON INTENSO Floodlights! Because only APPLETON-engineered INTENSO provides the accurately planned high intensity illumination, ease of servicing, cleaning, re-lamping, and positioning that gives maximum trouble-free, year-round lighting. Write for full information on the complete line of APPLETON Alzak Aluminum Floodlights!

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The friendly, relaxed atmosphere typical of modern living is created in this suburban supermarket with indirect lighting by Day-Brite. 134 eight-foot Power-Groove lamps deliver 70 to 100 footcandles of general illumination over an area of 16,000 square feet.

Your Day-Brite representative will be happy to recommend a lighting system adapted to your store's requirements, designed for maximum sales appeal and eye comfort, and tailored to your budget. Consult him without obligation. You'll find his name in the Yellow Pages.

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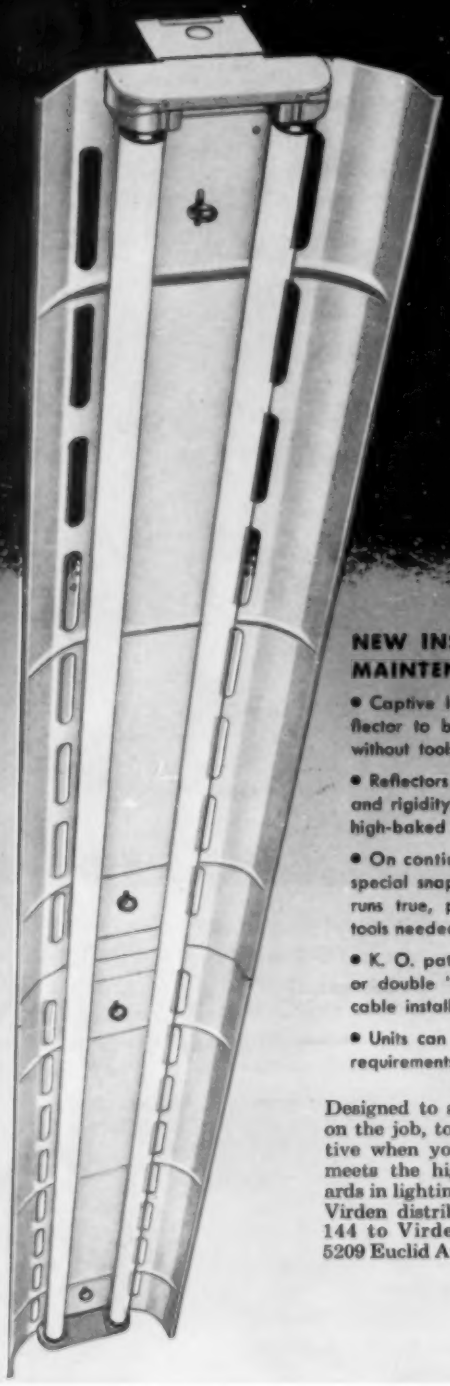

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- All plastic, with stainless steel springs. No rust or corrosion problems.
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- Captive latch device permits reflector to be installed or removed without tools.
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- Units can be fused to meet your requirements.

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A DIVISION OF THE JOHN C. VIRDEN COMPANY
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Designed to save you time and labor on the job, to keep you fully competitive when you bid. Fully efficient, it meets the highest established standards in lighting specifications. See your Virden distributor or write for Form 144 to Virden Lighting, Dept. IE, 5209 Euclid Avenue, Cleveland 3, Ohio.

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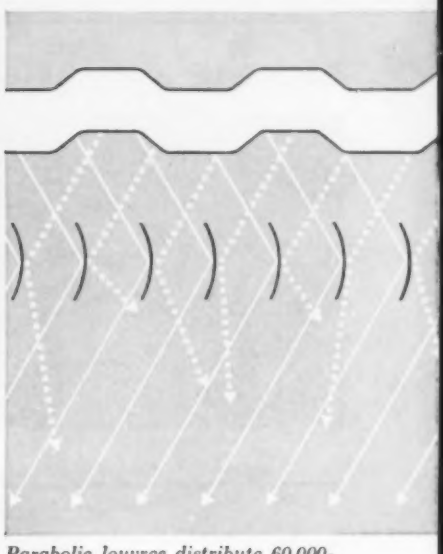
Smooth, comfortable illumination creates inviting appearance in store. Power-Lux installation provides over 200 footcandles using 12 Power Groove lamps.

Large-area Power-Lux luminaire combines high photometric efficiency with attractive, modern appearance.



Parabolic louvres distribute 60,000-lumen output for high-intensity, low-brightness illumination.

Over 200 footcandles with Power Groove lamps

New LPI Power-Lux luminaire for stores has been engineered for comfortable brightness using Power Groove lamps

Power Groove lamps are ideal for lighting stores when used with the new Power-Lux luminaire just introduced by Lighting Products Inc. One economical LPI Power-Lux with Power Groove lamps does the job of three conventional fixtures with slimline lamps. This lowers the cost of lighting installations as well as the cost per delivered lumen.

The very high light output of Power Groove lamps is controlled by LPI's exclusive parabolic louvres to provide high footcandle levels with comfortable brightness.

Power-Lux luminaires are available in a two-lamp model, 12 inches wide; and a four-lamp model, 36 inches wide. Both are offered in four- and eight-foot lengths. They are ideal for new stores as well as for raising lighting levels of existing commercial buildings. For re-lighting applications, Power-Lux luminaires can simply replace present fixtures to provide dramatic increases in illumination. **Get complete data on this new luminaire — write today for LPI's Power-Lux Bulletin.**

Lighting Products Inc. Highland Park, Illinois

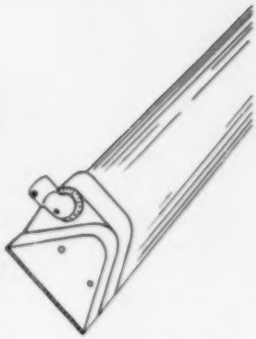
LPI FLUORESCENT LIGHTING

Revere Outdoor Lighting Report

Lighting a truck loading dock

The Problem: To light the entrance of a trucking depot loading dock. Light level must be high enough for safety and for precise parking of large trucks.

The Answer: Revere Fluoresign Outdoor Luminaires were installed over the doorways insuring safety, security and providing ideal visibility. This made nighttime parking as safe, fast and easy as daylight parking. The depot's eight entrances and its entranceway were lighted at the level of 12 to 15 footcandles with the all-weather fluorescent luminaires. Adjusting Fluoresign for best light spread can be done with lamps in and burning.

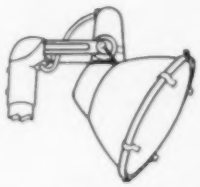


No. 8650 Series
Fluoresign Outdoor Luminaire

Lighting a tennis court

The Problem: To make night tennis play possible by providing the high level of uniform light required for good visibility in this high-speed game.

The Answer: Revere 4200 series floodlights mounted on Revere hinged poles were installed to provide the high level of light desired. Poles down the center of the courts have four floodlights, directed in pairs toward adjacent courts. Poles around perimeter of the court area have two floodlights each. Mounting height for all floodlights is 30 ft. Installation gives average maintained illumination of 13 footcandles.

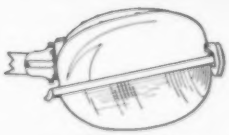


No. 4200 Series Floodlight

Lighting a shopping center parking lot

The Problem: To illuminate a large parking lot for safety in driving and parking, ease in locating parked cars, and to make the shopping center look more inviting.

The Answer: Revere Endoval Mercury Luminaires were used to illuminate driving lanes, and Revere No. 3350 Series Floodlights were installed to provide high-level illumination of 1.1 average maintained footcandles for the parking areas. The equipment is mounted on Revere hinged poles, using Revere brackets and arms. The hinged poles permit easier, safer, and more economical maintenance and relamping from the ground. Pole spacing is 150 ft.



No. 2282 Endoval
Mercury Luminaire

No. 3350 Series Floodlight

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In Canada: Curtis Lighting, Ltd., Leaside, Toronto, Ontario

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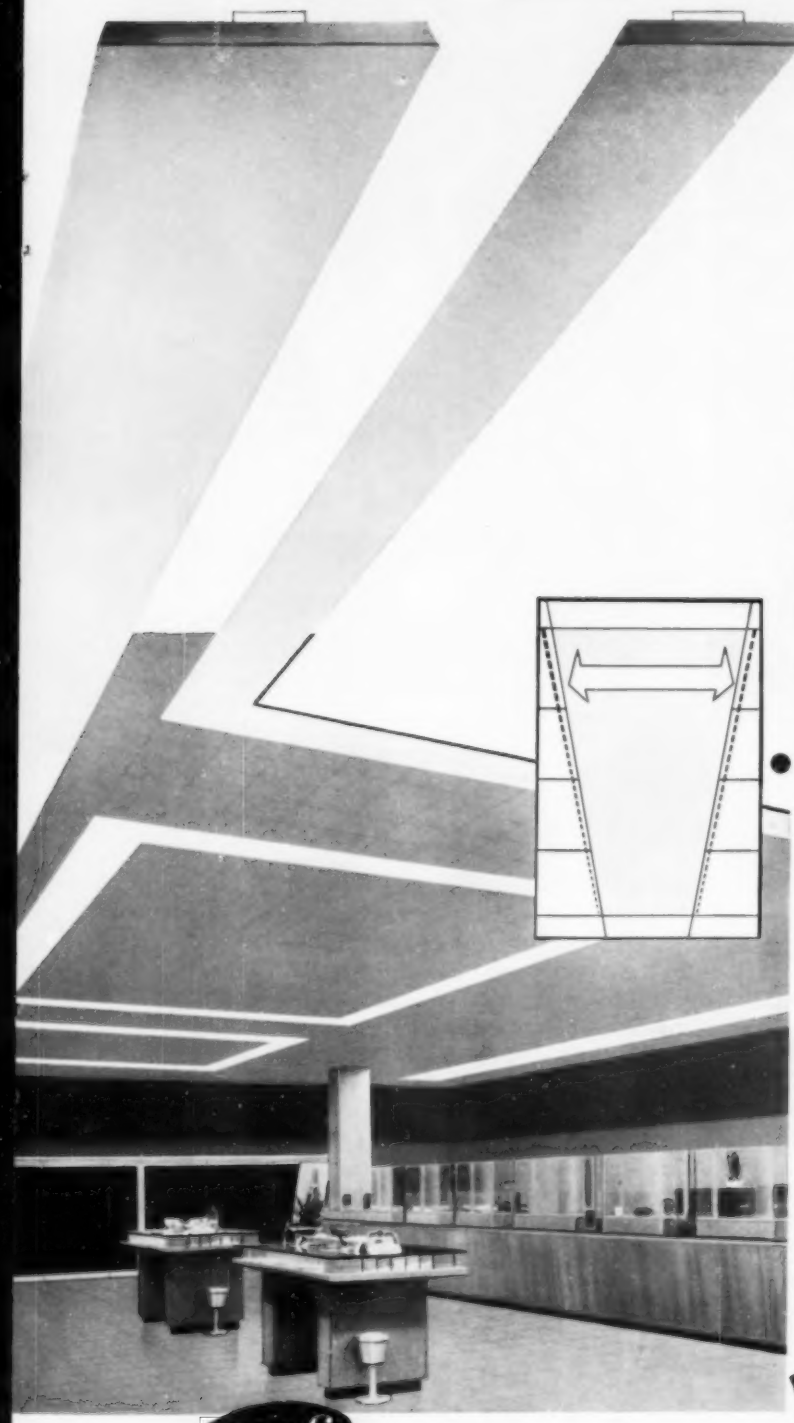

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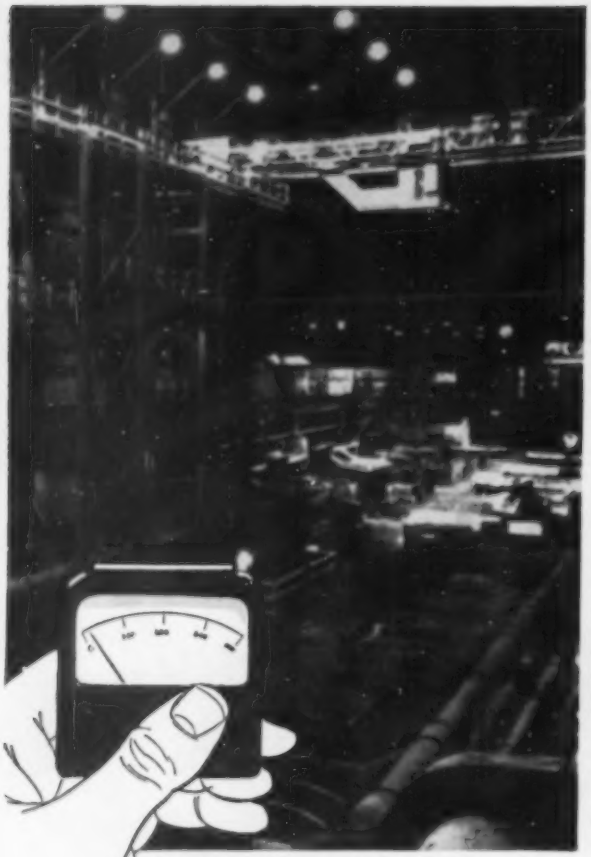
• • • WITH THE EXCLUSIVE TELESCOPIC DOOR FRAME

. . . that automatically expands or contracts to assure perfect fit even in irregular ceiling openings. The shielding medium is framed in the ceiling by a single width of metal, offering maximum illumination area and a clean, precise finished ceiling appearance, with no visible bolts, hinges, catches, etc. All of Smithcraft's complete series of one-foot and two-foot wide Speedomatic troffers are extremely easy to specify from Smithcraft's complete Ceiling Index. Installation of Speedomatic troffers is fast and efficient — the only tool needed is a screwdriver. Troffer installs in seconds from below by fast travelling levelling screws. Doors open and close easily, without mechanical catches, for easy maintenance.

For complete information on today's fastest-installing troffers, write for Smithcraft's Speedomatic folder. Also contains complete Smithcraft Ceiling Index and shielding information.

eye·fi RE/LIGHTING

America's finest fluorescent lighting **Smithcraft Lighting** CHELSEA 50, MASS.



Dull, dreary lighting *cuts down worker efficiency, causes eye strain, makes many work tasks hazardous.*

Improved lighting *pays off in higher output and greater accuracy, comfort and safety for workers.*

Lifting the lighting level

In the picture on the right, those Abolite fixtures provide a high level of comfortable, glareless light throughout this high bay building. 18% of the light is directed upward through Abolite's open top, washes out the deep shadows, gives lamps a soft background. 35° shielding of lamp practically eliminates glare.

Open-top design also gives Abolite high bay units a self-cleaning action. Air circulates through the fixture, sweeps reflecting surface clean.

Choose from several Abolite uplight units for high bay lighting: 18" and 24" Alzak aluminum fixtures for 400 and 1000 watt mercury lamps; and 14" and 18" fixtures for 300-500 watt incandescent lamps (ideal for gymnasium lighting). For full information, write *Abolite Lighting Division, The Jones Metal Products Company, West Lafayette, Ohio.*

Abolite Cat. No. HMFAU-2400 Alzak aluminum uplight fixtures with 400 watt white reflector Mercury lamps.

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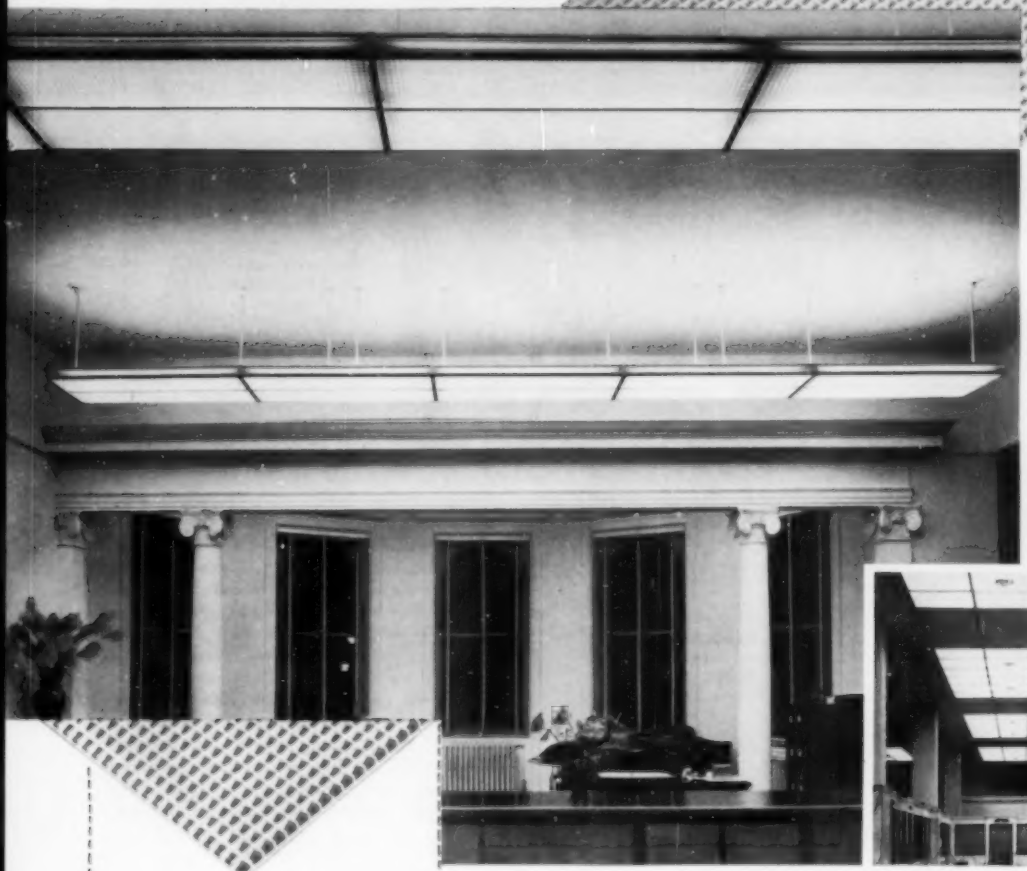
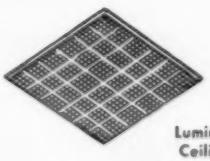
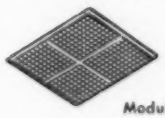
LEADING FIXTURE MANUFACTURERS *use* american plastic louvers . . .



- **Library Office .** *Lighting by Curtis*
- **Gary Bank** *Lighting by Sweeney Electric Co.*



Luminous Ceilings



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Pendant Fixtures

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American Plastic Louvers offer the maximum in conformability for any lighting plan, whether it be commercial, institutional, or industrial. They give soft—glare free, efficient inexpensive visual comfort. Maintenance free—self-aligning for individual fixtures, modular patterns or full ceiling installations.

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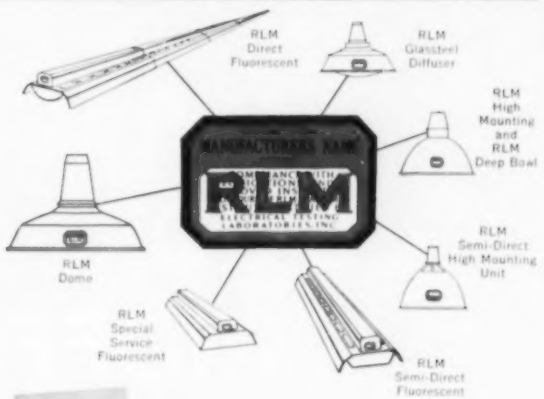

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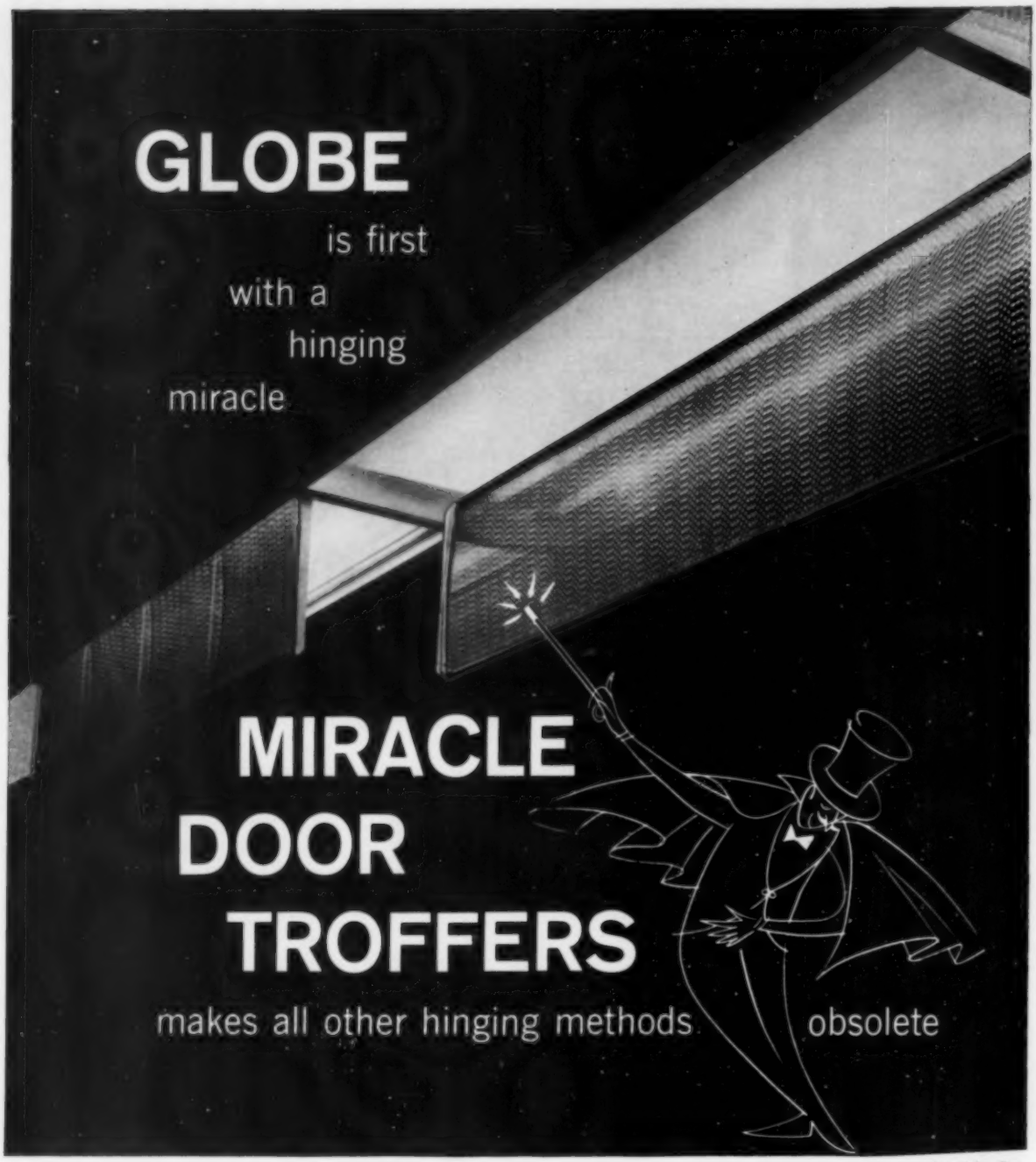

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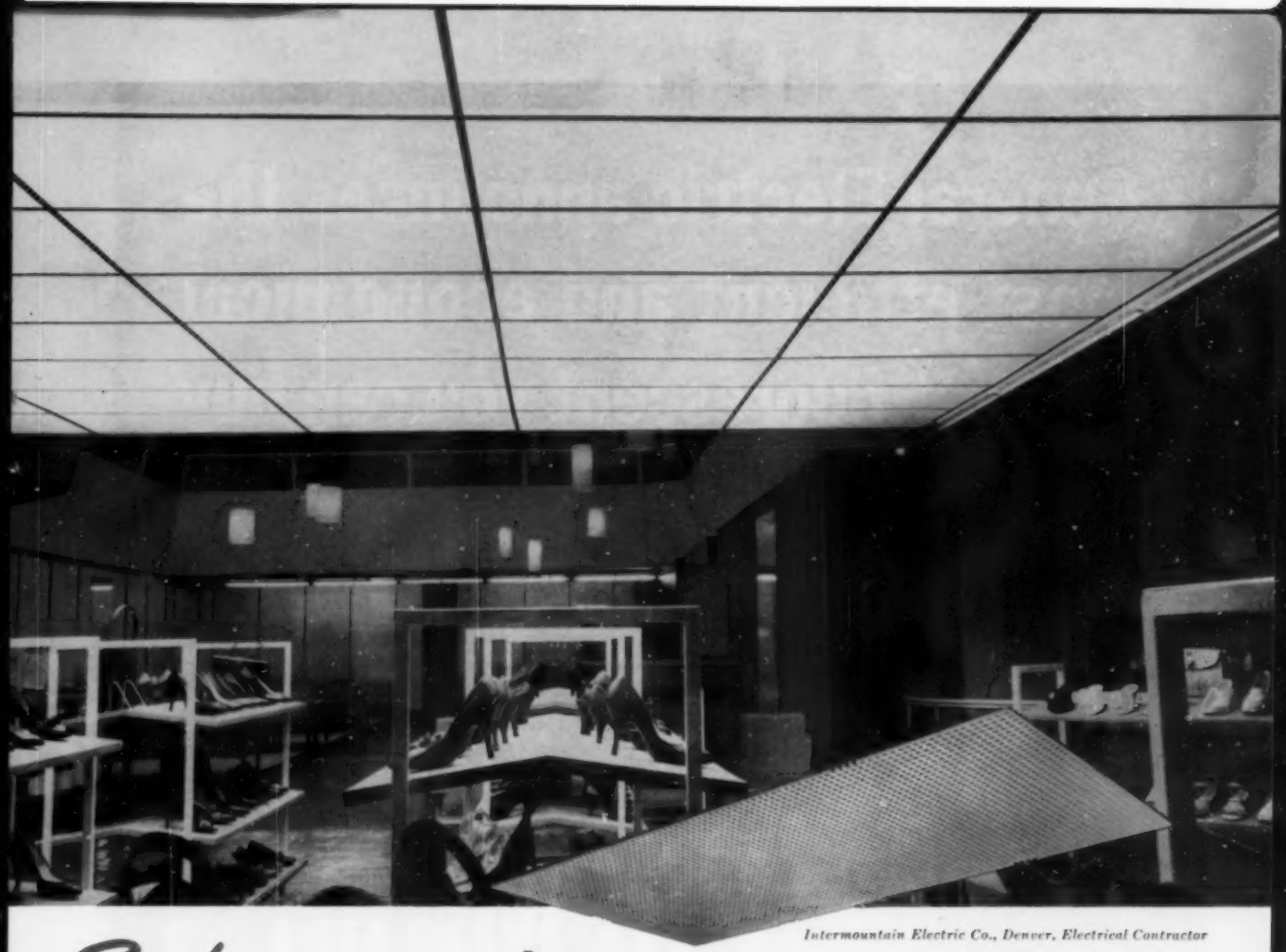

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Sinko LOW BRIGHTNESS Louvers ANSWERED THIS LIGHTING PROBLEM

Illuminating Engineer Carl Schranz of the Newman Schranz Lighting Company, in conjunction with Architect Richard L. Crowther, solved the lighting problem in The Fontius Shoe Store in Denver, in which Sinko Gray-Cell Louvers played an important part.

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SOLUTION—96" T 17 power groove, cool white lamps in fixtures suspended 30 inches above a luminous ceiling of Sinko's Lo-Brite, Gray-Cell, Plastic Louvers, supported in an aluminum inverted tee, grid system.

RESULT—This unusual treatment was the answer to obtaining the three A's of store lighting . . . attracting the customer . . . easy appraisal of merchandise . . . and a relaxing atmosphere.

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THE PREMIUM 3

3100 lumens

(Same preferred cool white as before)

Gives customers 17% more light from present fixtures!

G-E PREMIUM 3 Lamps give your customers the lowest over-all cost of light of any 40-watt lamp. Three new innovations provide added light worth more than the cost of the lamps themselves: 1) more efficient phosphors, 2) newly designed electrode mount, 3) new current-carrying gas mixture.

G-E PREMIUM 3 Lamps, the latest example of General Electric's lamp development, give your customers more for all their lighting dollars. G-E *Premium 3* Lamps operate on Rapid Start or Pre-heat (starter-type) circuits—and will be widely used to make existing systems deliver more light at virtually no added cost. Available in limited quantity in May, list price $1.45.

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1959—NEW POWER GROOVE. The most powerful fluorescent you can buy. Double row of grooves helps increase light output 12%, to 15,000 lumens for 8-foot length.

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(Continued from page 30A)

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(Continued on page 54A)

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(*Continued on page* 57A)

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Rectangular diffuser in 12" or 24" widths

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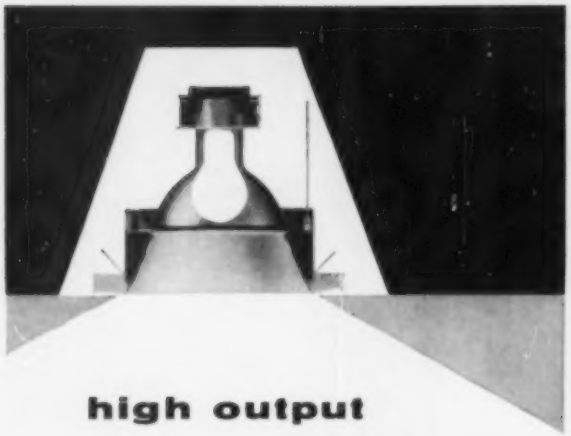

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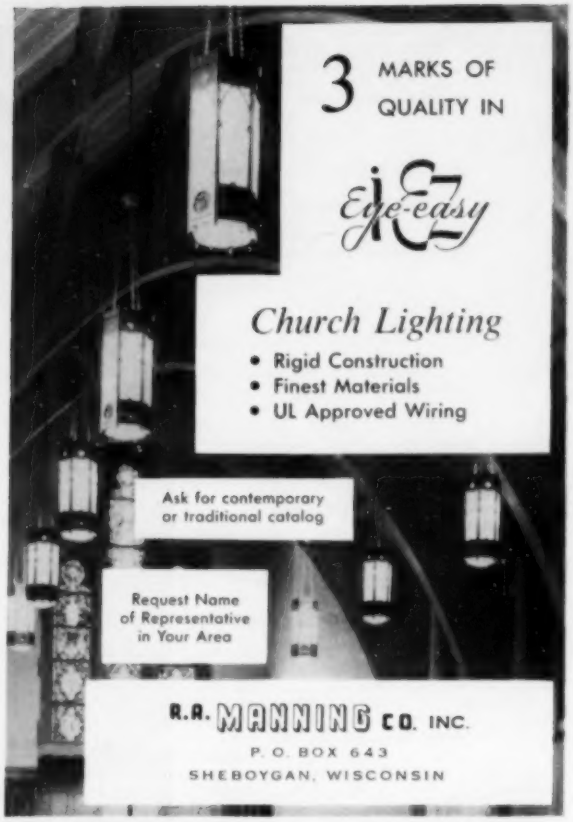

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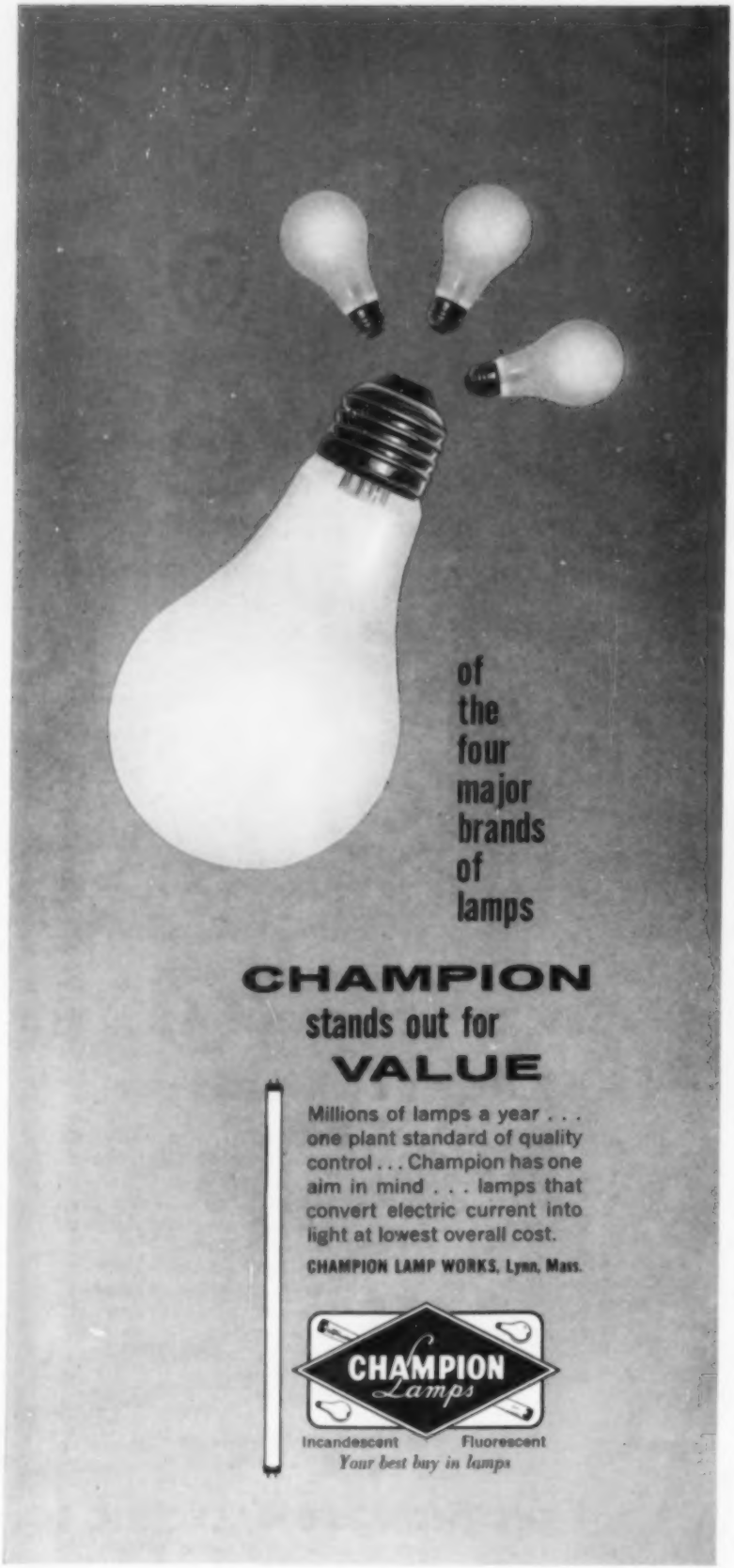

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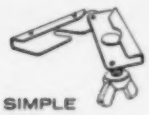

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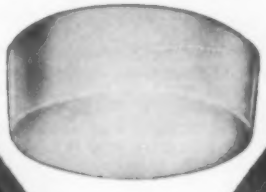

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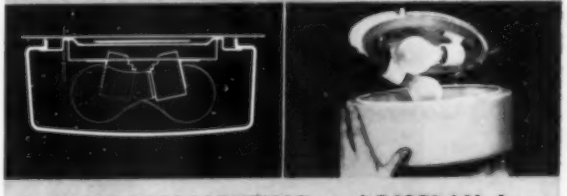

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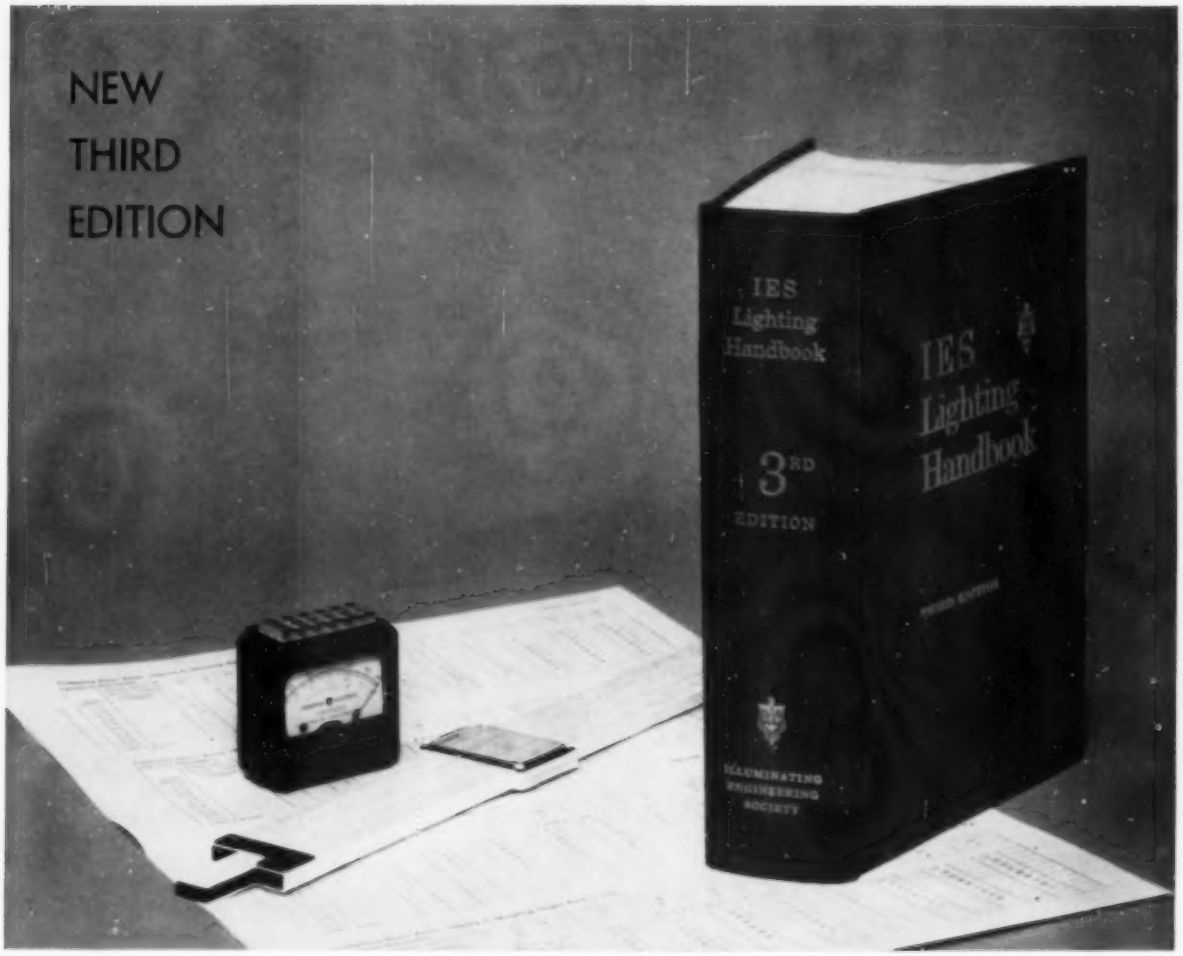
INDEX TO ADVERTISERS
June 1959

Abolite Lighting Division Jones Metal Products Co.	46A
Advance Transformer Co.	1A
American Louver Co.	47A
Appleton Electric Co.	39A
Architectural Ceilings Inc., Div. of Franklin Research Corp.	34A
Century Lighting Inc.	56A
Certified Ballast Manufacturers	41A
Champion Lamp Works	58A
Columbia Electric & Mfg. Co.	10A
Corning Glass Works	19A
Curtis-All Brite Lighting, Inc.	4A-5A
Day-Brite Lighting Inc.	40A
Dow Chemical Co.	13A
Garden City Plating & Mfg. Co.	55A
General Electric Co., Lamp	52A-53A
Globe Lighting Corp.	50A
Edwin F. Guth Co.	Back Cover
Holophane Co. Inc.	48A
Jefferson Electric Co.	14A-15A
Kent Lighting Corp.	54A
Lighting Dynamics	6A
Lighting Products Inc.	43A
Line Material Industries, Div. of McGraw-Edison Co.	32A-33A
Litecontrol Corp.	28A-29A
Major Equipment Co.	18A
R. A. Manning Co.	56A
McPhilben Lighting Co.	53A
Metalcraft Products Co. Inc.	26A
NL Corp.	59A
Paramount Industries, Inc.	31A
Perfeclite Co.	37A
Photo Research Corp.	56A
Reinhold Publishing Corp.	60A
Revere Electric Mfg. Co.	44A
RLM Standards Institute	49A
Rotuba Extruders Inc.	20A
Sinko Manufacturing and Tool Co.	51A
Smitheraft Lighting Div.	45A
Sola Electric Co.	24A-25A
Sunbeam Lighting Co.	23A
Sylvania Electric Products Inc.	2A, 38A
Thompson Electric Co.	57A
John C. Virden Co.	42A
Wakefield Co.	Inside Front Cover
J. A. Wilson Lighting & Display	59A
Daniel Woodhead Co.	59A



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